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# HUMAN FACTORS DESIGN CRITERIA for INERTIAL GUIDANCE EQUIPMENT

AC SPARK PLUG

THE ELECTRONICS DIVISION • GENERAL MOTORS CORPORATION

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| HUMAN FACTORS DESIGN CRITERIA FOR<br>INERTIAL GUIDANCE EQUIPMENT | ENGINEERING<br>DESIGN INFORMATION<br>EXHIBIT |
| | By: <br> Date: 1 May 1959 |

## INTRODUCTION

This exhibit was prepared for design engineers. It sets forth design principles and practices, both general and specific, to be used in designing inertial guidance equipment for maximum utilization by operator and maintenance personnel. The application of human factors principles in the design effort has proved to be a powerful factor in the acceptance and use of products and equipment. It is an accepted fact in modern industry that a knowledge of human factors engineering as an applied science and a research tool is essential to the design engineer to enable him to carry out his work most effectively. An awareness of the kinds of human factors data available, together with an understanding of the ways in which they can be employed in design should result in a better design effort and thus a better product.

The principles contained herein are by no means exhaustive. They represent only a part of the available data and knowledge on the subject; the part that the author believes to be most applicable to the design of inertial guidance equipment as experienced by previous design efforts. Due to the brevity of the principles listed herein, the users of this exhibit are urged to make liberal use of the listed reference material which will provide further guidance on those subjects covered in this exhibit and on those subjects not covered. Design engineers are also urged to make full use of their respective project's human factors representatives in implementing these design principles, working out optimal compromises when compromise is necessary, and for assisting design engineers in the solution of the many human factors problem areas covered in this exhibit that may arise.

The scope of this document can be ascertained by referring to the Table of Contents. It is realized that it may not be possible to conform completely to each requirement listed herein because of such other factors as economic feasibility, production methods, time phasing and the like. However, before discarding principles outlined herein in lieu of other factors, the design engineer is urged to strive for a level of compromise in areas of conflict and give precedence to the man component in the particular system or subsystem loop. It is in this way that the design engineer will be assured of a product designed for maximum efficiency and reliability; of a product designed for the user.

It should be noted that, despite the fact that this exhibit is not an attempt to recognize human factors shortcomings in present design criteria, it may, in some instances, conflict with criteria currently in use. Whenever recommendations contained herein conflict with such documents as the Instrument Design Manual, Drafting Manual, etc., personal discussion with the Human Factors Representative is invited.

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# 1. MAN-MACHINE SYSTEMS

## 1.1 General

The combination of man and machine to perform a given task is known as a man-machine system. The concept of man and machine interacting as system members represents a relatively new philosophy in design. Broadly interpreted, the term "machine" refers to any object used by the human being to accomplish a task; the man-machine system consists of man and machine working to attain a common goal. How efficiently this is done depends on how successfully the designer matches the demands of the machine to the capabilities and limitations of the man. Also, since the greatest amount of destructive potential as well as defensive measures lies with the equipment involved the mission of the equipment, the intended task it is to perform, and the strategic requirements are most important.

## 1.2 Equipment analysis

When carefully analyzed, equipment will fall into one of two categories: the machine favored design and the man favored design. The operator must be considered in the design of equipment in either category.

### 1.2.1 The machine favored design

In the machine favored design, the machine, as directed by the operator, accomplishes the desired work or is in itself, that part of the man-machine system which produces the desired results. This type of equipment generally calls for muscular activity and the movement of levers and other physical controls by the operator.

### 1.2.2 The man favored design

The machine's principal function in the man favored design is to inform the operator. The information received by the operator enables him to use judgment and make decisions. The system relies upon the physiological and psychological makeup of the operator for accurate transmission or interpretation of the information. This type of equipment is usually manipulated by small controls such as dials, knobs and switches, and involves less physical effort by the operator but more concentrated mental activity.

One of the major factors leading to increased efficiency of a man-machine system begins with an awareness of operator participation in the system. Equipment that will require a high degree of operator participation should receive the greatest consideration for the proper design of controls and the working environment of the operator. Where little operator participation is required, a simple design treatment should be used, with little regard to design of controls and operator environment.

1.3 Limiting design factors

In determining man-machine capabilities, consider that humans appear to surpass present-day machines in respect to ability to:

a. Detect small amounts of visual or acoustic energy.
b. Perceive patterns of light or sound.
c. Improvise and use flexible procedures.
d. Store large amounts of information for long periods and to recall relevant facts at the appropriate time.
e. Reason inductively.
f. Exercise judgment.

Present day machines appear to surpass humans in respect to the ability to:

a. Respond quickly to control signals, and to apply great force smoothly and precisely.
b. Perform repetitive, routine tasks.
c. Store information briefly and then to erase it completely.
d. Reason deductively, including computational ability.
e. Handle highly complex operations.

The machine, since it does not exist initially, allows the most latitude. Molding the machine to the job is essentially an engineering design problem requiring a knowledge of materials, techniques, and processes. In developing equipment to perform a specified task efficiently, fit the equipment to the man who will operate it. Include the design of controls, displays, control panels and work space. Poor instrument design, inadequate illumination, shortcomings in control design, or incorrect positioning of controls may cause excessive operator fatigue, may result in errors, may contribute to inefficient equipment performance, and may result in failure to accomplish the mission for which the man-machine system was intended.

1.4 Military human factors specifications

Military services now include a clause, similar to the following, in their procurement contracts that requires the adequate and timely consideration of human factors problems that may be encountered in the course of research and development work on military items:

"In all phases of the study, design, and development of systems and equipment called for in this specification, the contractor will utilize the services of a human engineering specialist or specialists in determining the existence of and solution to problems in: 1. Space for operators' stations in the arrangement and design of controls. 2. Design of visual displays and other means of supplying information. 3. Safety features. 4. Environmental conditions such as illumination, noise levels, vibration, temperature, and ventilation. 5. Utilization of skills already existent in available crews for improving the overall effectiveness of the system."

1.5 Summary of steps in the human engineering of inertial guidance equipment.

The following design schedule is based upon major stages that usually occur in the development of a system. Each stage is initiated and supported by one or more developmental documents. These stages and documents are discussed here in relation to the human factors engineering contributions that can be made in their preparation and the human factors engineering activities that should parallel their appearance. It should be noted that the stages presented in this schedule are not successive but often overlap or parallel one another.

1.5.1 Preparation of system requirements

1.5.1.1 Review the requirements for the system

1.5.2 Conduct of the design study (feasibility studies)

1.5.2.1 Study alternative capabilities

1.5.2.2 Prepare mission profiles for the airborne vehicle

1.5.2.3 Prepare flow charts for ground support equipment

1.5.2.4 Perform capability research

1.5.3 Development planning

1.5.3.1 Allocate functions within the airborne vehicle

1.5.3.2 Allocate functions within the ground support area

1.5.3.3 Perform a time and link analysis

1.5.3.4 Assign functions to individual crew members

1.5.3.5 Initiate research as indicated

1.5.4 Design of the development model

1.5.4.1 Prepare performance descriptions

1.5.4.2 Analyze individual operator work-loads

1.5.4.3 Study operator contacts

1.5.4.4 Perform operator performance research

1.5.4.5 Delineate usable crew station work areas

1.5.4.6 Delineate usable work areas within crew stations

1.5.4.7 Determine the location and installation of components

1.5.4.8 Perform research on alternative workspace layouts

1.5.4.9 Analyze human information requirements

1.5.4.10 Analyze human response requirements

1.5.4.11 Design displays, controls and operator consoles

1.5.4.12 Determine auxiliary job supports

1.5.4.13 Prepare procedures

1.5.4.14 Perform research for the integration and simplification of equipment.

1.5.5 Evaluation of the development model; testing and fabrication of the prototype model; production

1.5.5.1 Evaluate drawings, plans and blueprints

1.5.5.2 Evaluate mockup, development and prototype equipment

1.5.5.3 Evaluate engineering change proposals

## 2. VISUAL INDICATORS

### 2.1 General

An important factor in the design of equipment for maximum efficiency of human operation is the design, illumination and arrangement of visual displays which provide information to the human operator. The information displayed to each person who operates a piece of system equipment shall be limited to that information which is necessary to the specific actions or decisions required of him and shall be displayed only to the degree of specificity and accuracy required for the specific operator action or decision with which it is associated. Whenever possible, information shall be presented to the operator in directly usable form, that is requirements for de-coding, transpositioning, interpolation, etc., shall be minimized. Information necessary to different activities, e.g., operation and trouble shooting shall not be combined unless these are comparable functions requiring the same information. Indicators may be visual devices or aural devices. Visual indicators fall into three general types:

a. Numerical indicators
b. Pictorial indicators
c. Indicator lights

## 2.2 Numerical indicators

This type presents information by indicating a number. The number may represent a unit of measurement, or, if the condition cannot be interpreted in accepted units of measurement, the number may merely represent the relative degree to which the condition exists. There are three distinct sub-types of numerical indicators:

a. Moving pointer with a fixed scale
b. Moving scale with a fixed pointer
c. Counters

In addition, there are variations in the basic sub-types of numerical indicators:

a. Circular and curved scales with a moving pointer
b. Vertical and horizontal straight scales with a moving pointer
c. Circular and curved scales with a moving scale
d. Vertical and horizontal straight scales with a moving scale
e. Multiple pointer with a single scale
f. Multiple scale with multiple pointers
g. Moving pointer and counter combination
h. Moving pointer with a moving scale

### 2.2.1 Moving pointer with a fixed scale

The most advantageous feature of the moving pointer-fixed scale type indicator is that the position of the pointer can be observed quickly and from considerable distance, thus facilitating check readings.

#### 2.2.1.1 Circular and curved scales-moving pointer

The circular scale permits the maximum exposed scale length in a limited panel space. It provides for a compact instrument case. The long pointer and rotational movement aid in check and qualitative reading. The circular scale is preferred to the curved scale for most applications.

#### 2.2.1.2 Vertical and horizontal straight scales-moving pointer

This design is not recommended for general use. It is less compact than circular scales. The shorter pointer and lack of angular movement are less favorable for check reading.

### 2.2.2 Moving scale with a fixed pointer

The moving scale-fixed pointer type is inferior to the moving pointer type for most applications but does have advantages in some instances. A large range of values can be presented in a limited space and only a small section of scale need be exposed and illuminated.

2.2.2.1 Circular and curved scales-moving scale

The use of a fully exposed scale is usually not necessary. The partially exposed scale is generally recommended. This permits a long range of values in a limited panel space. Overlapping the covered scale portions also saves panel space.

2.2.2.2 Vertical and horizontal straight scales-moving scale

A moving scale behind an open window may be a moving straight scale, drum, or tape. The moving tape is suitable for presenting a large range of values that are to be read quantitatively. Moving scale designs are, however, not recommended for general use.

2.2.3 Counters

The counter type indicator is excellent for accurate reading of purely quantitative information of a large range of values. It is not generally satisfactory for presenting qualitative information, or for check reading. This indicator cannot economically be adapted to some applications because of the mechanical movement necessary to actuate it. For most applications with a large range of values this type is superior to the combination types of multi-revolution indicators discussed in 2.2.4. The counter is the most accurate means of indicating information being set into a piece of equipment. However, where rapid setting is required, the operator may be unable to read the quickly changing digits and may have to stop to see what the setting is.

2.2.4 Multi-revolution indicators

When a great range of values must be displayed on one instrument the conventional methods of presentation discussed in the foregoing sections are usually inadequate. It then becomes necessary to form combinations of some of the basic type indicators in order to cover the desired range of values. The reading error, however, for these types of indicators, is relatively high.

2.2.4.1 Multiple pointer-single scale

There is one sensitive multi-revolution pointer and one or more other pointers to give gross readings on this type of indicator. The reader must mentally combine several separately indicated values. The probability of gross reading errors is high. This method of indication is acceptable for indicating time, but is not recommended for general use.

2.2.4.2 Multiple scale-multiple pointer

When a limited scale range is to be presented, the wrist watch type of indicator is usually satisfactory, if for most purposes gross readings of the main pointer are adequate. The sub-dial is only used on those occasions requiring more precise readings. One revolution on the sub-dial should cover a range equal to a numbered interval on the main dial.

2.2.4.3 Moving pointer and counter combination

This combination is a generally recommended solution for long scale indicators for check and qualitative reading. It is slightly inferior to counters for purely quantitative reading.

2.2.4.4 Moving pointer-moving scale

This type of indicator though advantageous in certain isolated cases, is not recommended for general long scale use. The error probability in combining these two indications is very high.

Note: See Table 1 for a list of recommended indicators according to use.

2.2.5 General design of numerical indicators

2.2.5.1 Direction of indicator motion

There are several considerations that enter into the proper design of mechanical indicators. Some of these considerations deal with the direction of indicator motion. These are the direction of movement of the moving element in relation to (1) the numerical value being indicated, (2) the direction of the associated control movement, and (3) the direction of motion of the vehicle or component to which the instrument refers.

2.2.5.1.1 Moving pointer-fixed scale indicators-circular scales

2.2.5.1.1.1 Clockwise movement of the pointer should increase the magnitude of the reading.

2.2.5.1.1.2 In cases where positive and negative values around a zero value are being displayed the zero should be located at the nine or twelve o'clock position. The positive values should increase with clockwise movement of the pointer and the negative values increase with counter-clockwise movement.

TABLE 1 -- TABLE OF RECOMMENDED INDICATORS ACCORDING TO USE

| METHOD OF USE | MOVING POINTER | MOVING SCALE | COUNTER |
|---|---|---|---|
| 1. Quantitative Reading. | Fair | Fair | Good<br>Minimum time and error in obtaining exact numerical value. |
| 2. Qualitative and Check Reading | Good<br>Location of pointer easily detected. Numbers and scale need not be read. Change in position easily detected. | Poor<br>Difficult to judge direction and magnitude of deviation without reading numbers and scale. | Poor<br>Numbers must be read. Position changes not easily detected. |
| 3. Setting | Good<br>Simple and direct relation of pointer motion to motion of setting knob. Pointer position change aids monitoring. | Fair<br>Somewhat ambiguous relation to motion of setting knob. No pointer position change to aid monitoring. Not readable during rapid setting. | Good<br>Most accurate monitoring of numerical setting. Relation to motion of setting knob less direct than for moving pointer. Not readable during rapid setting. |
| 4. Tracking | Good<br>Pointer position readily monitored and controlled. Most simple relation to manual control motion. | Fair<br>No pointer position changes to aid monitoring. Somewhat ambiguous relation to control motion. Not readable during rapid changes. | Poor<br>No gross position changes to aid monitoring. Ambiguous relation to control motion. Not readable during rapid changes. |
| Comments | Requires greatest exposed and illuminated area on panel. Scale length limited unless multiple pointers are used. | Offers saving of panel space. Only small section of scale need be exposed and illuminated. Long scale possible by use of tape. | Most economical of space and illuminated area. Scale length limited only by number of counter drums. |

2.2.5.1.1.3 Clockwise movement of the pointer should result from (1) clockwise movement of the associated knob or crank, (2) movement forward, upward, or to the right of an associated lever, or (3) movement upward or to the right of the vehicle or component.

2.2.5.1.1.4 Except on multi-revolution instruments such as the clock, there should be a scale break between the two ends of the scale.

2.2.5.1.1.5 For ease of check reading quantitative values or for up-down orientation, the area of most frequent or critical reading should be located at the nine o'clock position on the dial face.

2.2.5.1.1.6 For ease of check reading bearing or course indication (or other right-left information) the area of most frequent or critical reading should be located at the twelve o'clock position. This may be accomplished by having a dial face that can be rotated manually.

2.2.5.1.1.7 In general it is better to place the numerals inside of the graduation marks to avoid constriction of the scale and hiding of numbers by the bezel. If space is not limited the numbers may be placed outside of the marks to avoid having the numbers covered by the pointer.

2.2.5.1.2 Moving pointer-fixed scale indicators-vertical and horizontal straight scales

2.2.5.1.2.1 The pointer should move up or to the right to indicate an increase in magnitude.

2.2.5.1.2.2 Movement of the pointer upward or to the right should result from (1) clockwise rotation of the associated knob or crank (2) movement forward, upward, or to the right of a lever, or (3) movement upward or to the right of the vehicle or component.

2.2.5.1.2.3 The numbers should be located on the side of the graduation marks opposite the pointer. The graduation marks should be aligned on the side of the pointer and stepped on the side of the numbers.

2.2.5.1.2.4 It is recommended that the pointer be to the right of vertical scales and at the bottom of horizontal scales.

2.2.5.1.3 Moving scale-fixed pointer indicators-circular scales

There exist certain ambiguities with moving circular scales and the associated control movement. One of the following three recommended practices must be violated in the design of circular moving scales:

a. Scale numbers should increase in a clockwise direction around the dial. Values on moving circular scales, therefore, increase with counter-clockwise rotation of the dial face.
b. The direction of movement of the associated control should be compatible with the direction of movement of the dial. (Clockwise movement of the control should result in clockwise movement of the dial.)
c. Clockwise movement of a control should result in an increase in function.

If principle one above is compromised (numbers on the scale increase in a counter-clockwise direction) operators tend to make final setting errors. If principle two above is compromised (clockwise movement of the control results in counter-clockwise movement of the dial) operators err in the initial direction of turn. If principle three above is compromised a standardized control movement-system relationship is violated. The following recommended practices in the design and use of circular moving scales will minimize the effects of these incompatibilities.

2.2.5.1.3.1 The numbers should progress in magnitude in a clockwise direction around the dial face. Therefore, counter-clockwise movement of the dial face increases the reading.

2.2.5.1.3.2 If the associated control has no direct effect on the behavior of the vehicle (monitoring electronic equipment) the scale should rotate counter-clockwise (increase) with counter-clockwise movement of the associated knob or crank.

2.2.5.1.3.3 If the associated control has a direct effect on the behavior of the vehicle (speed, direction, etc.) the scale should rotate counter-clockwise (increase) with (1) clockwise movement of the associated knob, wheel, or crank, (2) movement forward, upward, or to the right of a lever, or (3) movement forward, upward, or to the right of the vehicle or component.

2.2.5.1.3.4 The pointer or lubber line position should be at twelve o'clock for right-left directional information. For purely quantitative information either position may be used.

2.2.5.1.3.5 If the display is used for setting, such as tuning in a desired wavelength, it is usually advisable to cover the unusued portion of the dial face. The open window should be large enough to permit at least one numbered graduation to appear at each side of any setting.

2.2.5.1.3.6 If the display is used in tracking, as in the case of heading indicators, the whole dial face should be exposed.

2.2.5.1.4 Moving scale-fixed pointer indicators-vertical and horizontal moving straight scales

2.2.5.1.4.1 The same direction-of-motion ambiguities exist as in circular moving scales. The numbers should increase from bottom to top and from left to right.

2.2.5.1.4.2 The scale should move down or to the left (increase) when (1) the associated know or crank is moved clockwise, (2) when the associated lever is moved forward upward or to the right, or (3) the vehicle or component moves up or to the right.

2.2.5.1.5 Counter type indicators

2.2.5.1.5.1 The numbers should change by snap action in preference to continuous movement.

2.2.5.1.5.2 Clockwise rotation of a knob or crank should increase the counter indication.

2.2.5.1.5.3 An upward movement of a counter should indicate a numerical increase.

2.2.5.2 Scale design

This section offers recommendations concerning design principles for scales used on mechanical indicators. For the purpose of this discussion, the following definitions will apply to terms used within this section:

Scale range: The numerical difference between the highest and lowest value represented on a scale

Numbered interval value: The numerical difference between adjacent numbers on a scale

Graduation interval value: The numerical difference represented by adjacent graduation marks.

2.2.5.2.1 Scale numbering and graduation interval values

Some combinations of graduation interval values and scale numbering systems are more staisfactory than others. The recommendations below will assist in the selection of the readable scales.

2.2.5.2.1.1 The graduation interval values should be 1, 2, or 5 or decimal multiples thereof; no other values are acceptable.

2.2.5.2.1.2 Any scale should be represented as part of a scale which starts at zero with the numbered marks progressing by ones, twos, or fives, and with the appropriate number of zeros after each digit.

2.2.5.2.1.3 The numbered graduation marks should be major graduation marks.

2.2.5.2.1.4 The number of graduation marks between numbered graduation marks should not exceed nine

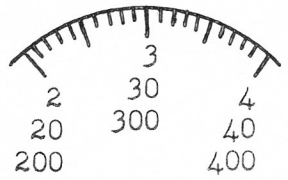
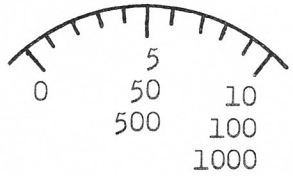
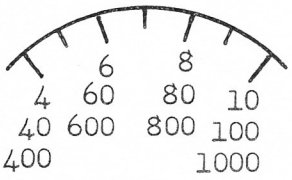
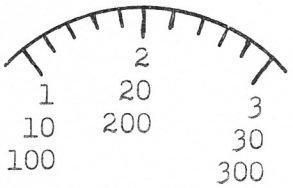
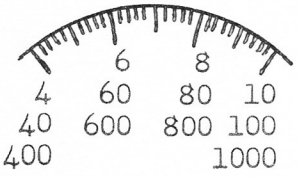
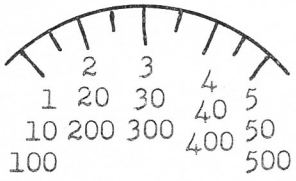
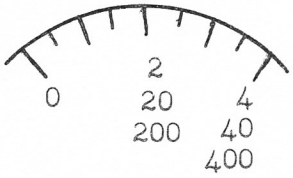
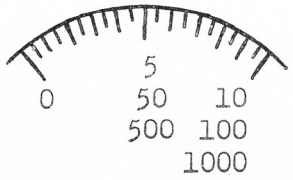
Before a designer selects a scale for a mechanical indicator he should decide on the appropriate scale range and should study the operator's task to estimate the precision required of the instrument reading. The scale should be designed to be read as accurately as demanded by the operator's needs, and preferably no more accurately. With this information in mind the designer may select from Table 2 the most suitable scale.

2.2.5.2.1.5 It is generally recommended that scales be designed so that interpolation between graduation marks is not necessary. However, when space is limited it is better to require interpolated readings than to clutter the dial with crowded graduation marks.

2.2.5.2.1.6 In general it may be said that scales numbered by intervals of 1, 10, 100, etc. and subdivided by ten graduation intervals are superior to other acceptable scales.

2.2.5.2.1.7 Nonlinear scales condense a large range into a relatively small space and yet permit sensitive readings at certain critical ranges of the scale. In situations where error tolerances are a constant

TABLE 2 -- TABLE OF RECOMMENDED SCALE DESIGNS

| Graduation Interval Value | Recommended Scales | Numbered Interval Value | Graduation Marks Used: Major | Minor | Intermediate |
|---|---|---|---|---|---|
| .1, 1, 10. |  | 1, 10, 100. | X | X | X |
| |  | 5, 50, 500. | X | X | |
| |  | 2, 20, 200. | X | | X |
| .2, 2, 20. |  | 1, 10, 100 | X | X | |
| |  | 2, 20, 200. | X | X | X |
| .5, 5, 50. |  | 1, 10, 100. | X | | X |
| |  | 2, 20, 200. | X | X | X |
| |  | 5, 50, 500. | X | X | X |

percentage of the indication, a logarithmic scale is very suitable. However, logarithmic scales should contain as many numbered graduation marks as possible, to minimize errors as a result of linear reading habits.

2.2.5.2.1.8 The absolute distance between adjacent graduation marks on scales in which the primary requirements are for accurate and rapid reading under a wide range of illumination conditions should not be less than .07 inches. The distance is measured from the graduation mark midpoints. The graduation mark thickness in this case should be approximately 50% of the graduation mark separation distance.

2.2.5.2.1.9 The distance between adjacent graduation marks on scales not requiring accurate and rapid reading and in an area that is reasonably well illuminated should not be less than .035 inches. The graduation mark thickness in this case should be about 25% of the graduation mark separation distance.

2.2.5.3 Instrument zone markings

On many instruments today, zone markings are employed to indicate the various zones of operating conditions. These markings may either be placed directly on the dial face or on the instrument windows if there is a frequent need for relocation because of varying conditions. The zone markings can be coded to convey such information as (1) desirable operating range, (2) danger-lower limit, (3) danger-upper limit, (4) caution, (5) dangerous vibration, (6) undesirable-inefficient, etc.

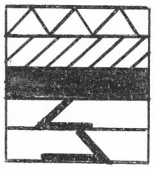
2.2.5.3.1 Color coding

The table below shows the recommended operating conditions to be associated with various colors of zone markings. Color coding should not be used if the instrument is illuminated with a colored light source because colors are not distinguishable when illuminated by colored sources.

| Color | Condition |
|---|---|
| red | danger |
| yellow | caution |
| green | desirable-one limit |
| blue | desirable-other limit |
| no marking | inefficient |

2.2.5.3.2 Shape coding

The shape or configuration of the zone markings can be coded to indicate various operating conditions. Shapes should be used, however, that are (1) easily learned associations, (2) distinguishable under low illumination, and (3) distinguishable under any color of illumination. The table below illustrates how shape coded zone markings can be used.

| Shape | Condition |
|---|---|
|  | danger |
| | caution |
| | desirable |
| | one limit |
| | other limit |

Note: See section 5. for information on numerals and letters used on instrument dials.

2.2.5.4 Pointer design

2.2.5.4.1 The pointer should extend so that the point will just meet, but not overlap, the shortest graduation mark.

2.2.5.4.2 The pointer tip should be as close as possible to the dial face, to minimize parallax.

2.2.5.4.3 For most applications the pointer section from the center of rotation to the point should be painted the same color as the dial markings. The balancing portion of the pointer should be painted the same color as the dial background.

2.2.5.4.4 When reciprocal readings are necessary from a single pointer the two ends of the pointer should be identifiable.

2.3 Pictorial indicators

Pictorial indicators present information by means of a pictorial representation of the actual situation. They usually indicate a position or attitude in relation to the position of the operator, a remote object or a datum point or line. Mechanical types of pictorial indicators such as artificial horizons are used extensively as aircraft instruments but their use is limited in ground equipment. For ground applications the pictorial indicator is usually electronic, the picture being presented on the face of a cathode ray tube. Grid lines, scales, electronic markers, and other markings permit qualitative or quantitative evaluation of the pictured situation. Because this exhibit is concerned only with those human factors principles applicable to inertial guidance equipment, this section will be limited to a discussion

of cathode ray tubes since other types of pictorial indicators have not as yet entered into the electronics field.

2.3.1 Cathode ray tubes

2.3.1.1 The display should resolve as much detail as is required for adequate interpretation of the displayed information.

2.3.1.2 The brightness contrast relationship between the signal and background should be sufficiently high to afford good visibility.

2.3.1.3 The viewing distance should be such that visual fatigue is minimized, and the viewing angle, i.e., the angle between the tube face and normal line of sight, should be such that visibility is maximized.

2.3.1.4 The ambient illumination in the cathode ray tube area should be sufficiently high for other visual functions (setting controls, reading instruments, maintenance, etc.) but should not interfere with the visibility of the signals on the cathode ray tube display.

2.3.1.5 The design of scales and other devices used to get quantitative data from the display should be such as to maximize accuracy and speed.

2.3.1.6 If information is to be coded, the coding methods used should provide a display that is easily interpreted.

2.4 Transilluminated indicators

Transilluminated indicators are generally used to display qualitative information to the operator. They will be used primarily to display that qualitative information which requires either an immediate reaction on the part of the operator, or that his attention be called to an important system status. Consideration should be given to the use of mechanical indicators or display devices other than transilluminated indicators for displaying routine, expected system status.

2.4.1 Color coding

In an attempt to minimize variations in interpretation, these criteria associate colors primarily with types of operator action (what he should do or has done) rather than with various system or equipment conditions.

2.4.1.1 Red

Red shall be used to alert an operator that the system or any portion of the system is inoperative and that a successful mission is not possible until appropriate corrective or override action is taken. Examples of lights which should

be coded red are those which display such information as: no-go, error, failure, malfunction, etc.

2.4.1.2 Amber

Amber shall be used to advise an operator that a condition exists which is marginal insofar as system effectiveness is concerned, that an unsatisfactory or hazardous condition is being approached or exists but that the system can still operate (battery approaching replacement time, etc.)

2.4.1.3 Green

Green shall be used to indicate that a unit or component is in tolerance or a condition is satisfactory and that it is all right to proceed (go ahead, in tolerance, ready, acceptance, normal, etc.) and that the operator should apply normal monitoring and/or operating procedures.

2.4.1.4 White

White shall be used to indicate those system conditions that are not intended to provide a right or wrong implication, such as indications of alternative functions (air burst-ground burst, no. 1 - no. 2, etc.) or are indicative of transitory conditions (action or test in progress), where such indication does not imply success of operations.

2.4.2 General principles

2.4.2.1 Transilluminated indicator lights, used solely for maintenance and adjustment and referred to infrequently, shall be covered during normal operation but shall be readily accessible and visible to the operator or maintenance man when required.

2.4.2.2 Master caution, master warning and summing lights used to indicate the condition of the entire subsystem shall be set apart from the lights which show the status of the subsystem components. This will aid both the supervisor and operator in determining quickly the status of the entire subsystem.

2.4.2.3 Do not use lights solely to indicate switch or control position unless the switch position is not or cannot be made apparent by proper design of the control. Lights should be used to display equipment response and not merely switch position.

2.4.2.4 If it is necessary to have many lights on a control panel a master light test control should be incorporated. If this

is not feasible, each indicator shall be designed for "press-to-test" bulb testing. Even more desirable are devices which test the operation of the total indicator circuit.

2.4.2.5 When a control is associated with a transilluminated indicator, the indicator light shall be so located as to be immediately and unambiguously associated with the control. In almost all instances the light should be located above the control.

2.4.2.6 The brightness of transilluminated indicators shall be compatible with the ambient illumination level expected. They shall be several times as bright as the background against which they appear but not so bright as to dazzle the operator. When used under varied ambient illumination, a dimming control with limited range should be provided. The range of the dimming control shall be so limited at the lower adjustment that the lights will still be visible under the brightest expected ambient illumination. If panels are to be used outdoors, provisions shall be made to prevent reflected sunlight from making the indicator appear as illuminated.

2.4.2.7 Lights used to denote emergency conditions (personnel or equipment disaster) and only those indicating such conditions will be coded in flashing red. The flash rate for flashing warning lights may vary from 3 to 5 flashes per second with on time being approximately equal to off time. The indicator shall be so designed that is energized and the flasher device fails, the light will come on and burn steadily.

2.4.2.8 The effectiveness of warning lights as attention getting devices decreases with distance from the center of the visual field. For critical functions the indicator shall be located within $30^{\circ}$ of the normal line of sight. Also, it is desirable to have the warning light integral with, or adjacent to, the lever, switch, or other control device by which the operator is to take action.

2.4.2.9 For ease of maintenance, provision shall be made for bulb removal without the use of tools from the front of the display panel or other equally rapid and convenient means. The filter caps and/or legend plates shall be physically coded (or captive) so as to preclude the possibility of a mismatch.

2.4.3 Types of transilluminated indicators

Transilluminated indicators presently used are of two general types: simple type indicators (pilot lights, bulls-eye lights, jewel lights, etc.) and single and multiple type legend indicators.

Legend lights present information in the form of meaningful words, numbers, symbols or abbreviations. Indicator lights shall preferably be transilluminated legend lights. The use of jewel type lights is not recommended and shall be limited to circumstances wherein,because of space or wiring requirements, legend indicators cannot be used.

2.4.3.1 Legend type indicator lights

2.4.3.1.1 Legends shall be inscribed directly on indicator lights.

2.4.3.1.2 All legends when not transilluminated, shall be visible to the operator under normal lighting conditions.

2.4.3.1.3 All legend indicators shall be of uniform design as follows: Black legends shall be utilized on non-reflecting white backgrounds. The appropriate color coding, as specified in 2.4.1 above, shall be obtained by the use of colored filters behind the white background. An exception to this is taken in cases where the legend can change to indicate more than one condition. In such cases the legend may be either illuminated or black with illuminated background.

2.4.3.1.4 If it is desirable to display both the satisfactory operation of a unit and its failure (or malfunction) two alternatives are available: (1) Employ two vertically adjacent (stacked) indicators, or (2) Use one indicator for both types of information. In the latter case the change may be accomplished by changing both the legend and the code color, or by merely changing the code color alone. However, if only the code color changes, the meaning of the legend and the color shown shall be compatible.

2.4.3.1.5 Legends shall be clear and straightforward. Where labeling standards apply they shall be used. Legibility standards for letters and numerals used on legend indicators are as outlined in section 5.

2.4.3.1.6 Where the total legend can be accommodated within the dimensions of the indicator light, no abbreviations shall be used. In all other cases, standard abbreviations shall be used.

2.4.3.1.7 Shape and size of legend indicators.

2.4.3.1.7.1 General status indicators shall preferably be rectangular in shape and as close as possible to 1 1/2 inches wide by 3/4 inch high. The use of

square legend indicators is generally less desirable. However, if necessary, they may be used but their dimensions should approximate 3/4 inch square.

2.4.3.1.7.2 Emergency and/or failure indicators shall retain these shape requirements but shall be larger than general status indicators in size. In no case, however, shall the dimensions of emergency and/or failure indicators exceed twice those used for general status indicators.

2.4.3.1.8 Legend indicators shall be so constructed that legends cannot be interchanged. An effort shall be made to use light fixtures with front access to lamps.

2.4.3.1.9 Dual bulbs shall be employed to insure illumination in the event of a bulb failure during critical type operations.

2.4.3.2 Simple-type indicator lights

2.4.3.2.1 Simple type indicator lights will be used in those cases appropriate to the general use of transilluminated indicators where it is not feasible to use legend indicators.

2.4.3.2.2 For use at an approximate viewing distance of 28 inches the spacing between the adjacent edges of simple-type indicator light fixtures should be at least 3/4 inch.

2.4.3.2.3 Simple-type indicator lights shall be color coded in conformance with section 2.4.1 above. If simple-type indicator lights must be used for emergency conditions (personnel or equipment disaster) such functions shall be indicated by a 1 inch diameter red flashing light and cautionary conditions (impending danger) by a 1 inch diameter steady amber light. Master summation indications, system or sub-system, will be indicated by 1 inch diameter steady red or green lights. Indication of all other conditions will be 1/2 inch diameter steady lights. All 1 inch diameter lights will be approximately twice the apparent brightness of the 1/2 inch diameter lights. With the exception of small flashing white call lights commonly used on communication panels, no other flashing lights will be used.

2.4.3.2.4 The use of neon illuminated simple-type indicators should be avoided if possible because of the low level of illumination inherent in neon lamps.

2.5 Check list for a good indicator

Listed below are the characteristics of a good indicator. In general they are a summary of the more salient principles listed in the foregoing sections and should serve as a check list for the designer.

2.5.1 It can be read quickly in the manner desired (i.e., quantitative, qualitative, and check)

2.5.2 It can be read as accurately as demanded by the operator's needs, and preferably no more accurately.

2.5.3 It is free of features which produce ambiguity or invite gross reading errors.

2.5.4 The information is provided in the most immediately meaningful form, not requiring mental translation into other units.

2.5.5 Changes in indication are easy to detect

2.5.6 The indicator is easily identified and distinguished from other instruments

2.5.7 It tells the operator which controls to use in changing its reading

2.5.8 It tells the operator in which direction to operate the controls.

2.5.9 The information is current, i.e., lag is minimized

2.5.10 If inoperative, the instrument cannot be read or the operator is properly warned.

3. CONTROLS

3.1 General

A control is defined as that part of the equipment which is provided for the operator's use in order to effect a change in equipment's performance. The nature of the controls selected will have a direct effect upon the efficiency of operator performance and the overall efficiency of the man-machine system. Because of the infinite variety of controls, only those basis types used on inertial guidance equipment will be covered in this section.

3.2 Selection of proper control

There are no "good" or "poor" controls as such; the goodness of any control depends upon its appropriateness to the task for which it is assigned. A control which is satisfactory for one task may be inadequate for another. The first step in selecting the proper control is to determine the following:

a. Function of the control: Its purpose and importance to the system. The nature of the controlled object, the type of change to be accomplished, the extent and direction of change.

b. Task requirements: The precision, speed, range and force requirements in using the control, the effect of reducing one of these requirements in order to improve another.

c. Informational needs of the operator: The operator's requirements for locating and identifying the control, determining the control position (setting), sensing any change in control position.

d. Workplace requirements: The amount and location of available space in which to place the control, the importance of locating the control in a certain position in order to assure proper grouping and/or association with other equipment, controls and displays.

3.2.1 Rules for control selection

3.2.1.1 Select controls which permit each limb to be used effectively. When an operator is involved in a complex task, the controls should be distributed so that no one limb will be overburdened.

3.2.1.2 Select controls whose movements conform with those of the controlled display, equipment component or vehicle. The direction of movement of the control should be consistent with that of the controlled object or display.

3.2.1.3 Use multirotation controls when high precision is required over a wide range of adjustments. Linear movements can be made as precisely as rotary ones. Hence for small adjustments of the controlled object, either a linear or a rotary control is satisfactory. However, since the range of movement of a linear control is generally limited, this type of control does not permit high precision over a wide range of adjustments. With a multirotation control, any desired precision can be obtained by appropriate gearing (although this may affect operating time).

3.2.1.4 Use discrete adjustment (detent) controls rather than continuous adjustment (non-detent) controls when performance requirements are such that the controlled object can be adjusted in a limited number of discrete steps. Discrete adjustment controls (i.e., controls which snap into place for a limited number of positions), when properly designed, can be positioned with one gross adjusting movement. Continuous adjustment controls are generally positioned in two steps (a slewing movement and a fine adjustment). Continuous adjustment controls must be used when precise adjustments are needed along a continuum or when a large number of settings

(usually more than 24) is required. However, when a limited number of settings is required or when precision requirements are so gross that a limited number of settings can represent an entire continuum within the required accuracy, discrete adjustment controls are preferred.

3.2.1.5 When force and range of settings are the primary considerations in control selection, use the control recommended below.

3.2.1.5.1 For small forces:

a. For 2 discrete settings - use hand push button, foot push button or toggle switch

b. For 3 discrete settings - use rotary selector switch or toggle switch (if a three position rotary control is less satisfactory).

c. For 4-24 discrete settings - use rotary selector switch

d. For small range of continuous settings - use knob or lever

e. For large range of continuous settings - use crank.

3.2.1.5.2 For large forces:

a. For 2 discrete settings - use detent lever, large hand push button or foot push button

b. For 3-24 discrete settings - use detent lever

c. For small range of continuous settings - use hand-wheel, rotary pedal or lever

d. For large range of continuous settings - use large crank

3.2.1.6 Use combined controls rather than individual ones when they serve certain purposes. Several functionally related controls can be combined for purposes such as:

a. Reducing reaching movements

b. Aiding in sequential or simultaneous operation of controls

c. Economizing on use of panel space for control mounting.

In combining controls, care must be taken not to violate other human factors principles. The hazard of accidental activation should be especially considered.

3.2.1.7 Select controls which are easily identified. All controls should be identifiable, primarily by standardizing their locations but also by other means such as shape and size coding and color coding when appropriate. Primary and emergency controls should be identifiable both visually and non-visually. Identification (coding) should not hinder the operator in manipulating his controls or increase the likelihood of accidental activation.

3.3 Prevention of accidental activation

It is desirable to design and locate controls so that they are not susceptible to being moved accidentally. It is particularly important that critical controls, ones whose inadvertent operation can result in equipment or personnel hazards or in delays, be protected against inadvertent operation. It may also be necessary to so protect "internal" or "hidden" controls since it is usually not obvious that such controls have been disturbed and since it is usually difficult and time consuming to locate and readjust these controls. Occasionally it is also desirable to protect a control simply to prevent it from being operated in haste. However, any method of so protecting a control may also preclude its being operated quickly when desired. For the situations in which controls need to be protected, the method of protection will conform to one or more of the following:

3.3.1 Locate and orient the control so that the operator is not likely to hit or move it accidentally in the normal sequence of control movements.

3.3.2 Recess, shield or place physical barriers around the control.

3.3.3 Cover or guard the control. This method is not recommended if the control is used frequently unless the guard can be locked out of position.

3.3.4 Provide interlocks so that extra movement (e.g., a side movement out of a detent position, a pull-to-engage clutch, etc.) or the prior operation of a related or locking control is required. This method is not recommended if frequent operation of the individual control is required.

3.3.5 Build resistance, friction and spring loading, viscous damping, or inertia into the control so that definite and/or sustained effort is required to actuate it.

3.4 Control characteristics

The most commonly used controls (four discrete adjustment and five continuous adjustment controls) and the most important characteristics of each are listed in this section. All nine controls are compared in Table 3 for use in selecting the proper control for various tasks. (For detail design recommendations for each control, see section 3.5).

3.4.1 Hand push button

3.4.1.1 Consists of three major types: (1) push-on and release-off, (2) push-on and push-off, (3) push-on and lock-on.

3.4.1.2 Requires little space for location and operation

3.4.1.3 Can be operated quickly and simultaneously with other push buttons in an array. Easily identified by its position within an array or by its associated display signals.

3.4.1.4 Easily coded by color or size. However, control setting (whether on or off) is not easily identified either visually or non-visually. (An exception to this is the lighted push button).

3.4.1.5 Very quickly actuated. Operating time increases with excessive displacement and/or force.

3.4.1.6 Direction-of-movement relationships are usually not a consideration; therefore, may usually be placed anywhere around the operator and move in any direction.

3.4.2 Foot push button

3.4.2.1 Consists of two major types: (1)push-on and release-off, (2)push-on and push-off.

3.4.2.2 Leaves hands free for other operations.

3.4.2.3 Requires large space for operation because of the swept volume of the foot.

3.4.2.4 Because it usually cannot be seen or felt (without danger of activating it), neither the control nor its setting (whether on or off) is easily identified.

3.4.2.5 Quickly actuated when foot is on control. Operating time increases with increase in required displacement and/or force. Toe-operated controls are actuated slightly faster than heel-operated ones.

3.4.3 Toggle switch

3.4.3.1 Usually has two positions. May have more but speed and ease of operation are sacrificed.

3.4.3.2 Requires little space for location and operation

3.4.3.3 Can be operated quickly and simultaneously with other toggle switches in a row. Identified easily by its proximity to its display or by its location within an array.

3.4.3.4 Control setting (position) is identifiable both visually and non-visually.

3.4.3.5 Very quickly actuated.

3.4.4 Rotary selector switch

3.4.4.1 Usually has between 3 and 24 settings (positions). May have more, but speed and accuracy of setting and checking are sacrificed.

3.4.4.2 Requires more space for location than do push buttons or toggle switches, plus some additional space for operation because of the swept volume of the hand. However, when a large number of discrete settings are required, one rotary selector switch requires less space than an array of push buttons or toggle switches.

3.4.4.3 Easily identified by color or shape. Control setting (position) is visually identifiable; can be identified non-visually with proper design.

3.4.4.4 Quickly actuated

3.4.4.5 Can be used with either a rotatable indicator (pointer) and stationary numbers or a stationary indicator and numbers on a rotatable skirt.

3.4.5 Knob

3.4.5.1 Effective for making small turning operations which do not require the application of large forces.

3.4.5.2 Requires more space for operation than do push buttons and toggle switches because of the swept volume of the hand.

3.4.5.3 Easily coded by color, size or shape. Control setting (position) is visually identifiable provided the control makes less than one rotation and has a pointer or marker attached.

3.4.5.4 Can have an unlimited range of control movement; with proper gearing can be used for either gross or fine positioning over a wide range of adjustments.

3.4.5.5 Can be "ganged" with other knobs by mounting knobs on concentric shafts. Mounting more than two knobs on concentric shafts is likely to be wasteful of panel space, but may be desirable for other reasons such as facilitating sequence of operations.

3.4.5.6 Folding crank handle can be attached to aid in rapid slewing.

3.4.5.7 Can be used with either a rotatable indicator (pointer) and stationary numbers or a stationary indicator and numbers on a rotatable skirt.

3.4.6 Crank

3.4.6.1 Effective in making adjustments on a continuum where large distances must be covered and high rates of turning are required. (For slower rates a knob or handwheel is more effective.)

3.4.6.2 Requires more space for location than do small controls (push buttons and toggle switches), plus some additional space for operation (turning) because of the swept volume of the hand.

3.4.6.3 Because it is usually multi-rotational, the position of the handle generally does not indicate the control setting (position).

3.4.6.4 Can have an unlimited range of control movement; with proper gearing can be used for either gross or fine positioning over a wide range of adjustments.

3.4.6.5 Can be attached to a knob or handwheel for increased versatility.

3.4.7 Handwheel

3.4.7.1 Usually operated by both hands but operable with one.

3.4.7.2 Useful for exerting greater rotary forces than are possible with knobs and cranks.

3.4.7.3 Requires large amount of space for location and operation.

3.4.7.4 Can be coded by color effectively. Identification of control setting (position) is poor, and impossible if multiple rotations are permitted.

3.4.7.5 Useful as part of a combined control. Smaller controls (push buttons, knobs, etc.) can usually be attached easily. However, their position may vary with the position of the handwheel, thus potentially interfering with their operation.

3.4.7.6 For most effective use, the usual arc of rotation should not exceed $\pm 60^{\circ}$ from the normal (null) position. Larger arcs require the hands to shift position on the control.

3.4.8 Lever

3.4.8.1 Includes joystick, gear shift, throttles, etc.

3.4.8.2 Most effective when it moves through an arc of not more than 90°. Should never exceed the convenient reach of the arm.

3.4.8.3 Requires more space than do small controls (push buttons, toggle switches).

3.4.8.4 Easily coded by color, size or shape. Identification of control setting (position) is fair both visually and non-visually.

3.4.8.5 Has a limited range of movement; therefore, is generally unsatisfactory for precise positioning over a wide range of adjustments.

3.4.8.6 Can be operated quickly and simultaneously with other levers in a row.

3.4.8.7 Smaller controls (push buttons, toggle switches, triggers, etc.) can be attached easily, making one combined control.

3.4.8.8 Enables a seated operator to exert large forces against the control in a fore-aft direction.

3.4.9 Pedal

3.4.9.1 Consists of three major types: (1) rotary, (2) reciprocating, (3) translatory.

3.4.9.2 Requires more space for location than do small controls, plus some additional space for operation.

3.4.9.3 Because it usually cannot be seen or felt (without danger of activating it), neither the control nor its setting (position) is easily identified.

3.4.9.4 Permits more force but less precision and speed than do hand controls.

3.4.9.5 Rotary pedals have unlimited range of control movements; therefore, with proper gearing can be used for either gross or precise positioning over a wide range of adjustments. Reciprocating and translatory pedals have limited ranges of control movement; therefore, are unsatisfactory for precise positioning over a wide range of adjustments.

3.5 Detail design recommendations for specific controls

This section presents detailed recommendations for the design of the nine most commonly used controls defined in the preceeding section. The following design factors are covered for each control:

a. Size: Recommended dimensions (maximum and minimum)

b. Displacement: Recommended range of control movement and when applicable, optimum control-display ratio.

c. Resistance: Recommended amounts and types of resistance to be built into each control.

Note: For toggle switches, handwheels, cranks and levers, resistance is described in terms of linear resistance (i.e., the resistance at the point where the operator applies force to the control) rather than torque. For these controls, operator output can normally be considered as a force relatively independent of control radius.

For cirular knobs resistance is described in terms of torque. The force which can be brought to bear on the control is a function of the "efficiency" of the operator's grasp (i.e., the amount by which the fingers must be spread, etc.), which, in turn is related to knob diameter.

d. General: Certain design recommendations specific to a given control but not generally applicable to all controls.

3.5.1 Hand push button

3.5.1.1 Size

3.5.1.1.1 Minimum diameter for fingertip operation: 1/2 inch

3.5.1.1.2 Minimum diameter for emergency controls which can be activated by thumb or heel of the hand: 3/4 inch

3.5.1.1.3 Maximum diameter: No limitations set by operator performance

3.5.1.2 Displacement

3.5.1.2.1 Minimum: 1/8 inch

3.5.1.2.2 Maximum for operation by thumb or fingertip: 1 1/2 inches

3.5.1.3 Resistance

3.5.1.3.1 Minimum for fingertip operation: 10 ounces

3.5.1.3.2 Maximum for fingertip operation: 40 ounces

3.5.1.4 General

TABLE 3 -- TABLE OF CONTROL CHARACTERISTICS

| CHARACTERISTICS | TYPE OF CONTROL: DISCRETE ADJUSTMENT | | | | CONTINUOUS ADJUSTMENT | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Hand push button | Foot push button | Toggle switch | Rotary selector switch | Knob | Crank | Hand-wheel | Lever | Pedal |
| Large forces can be developed | -- | -- | -- | -- | No | Yes | Yes | Yes | Yes |
| Time required to make control setting | Very quick | Quick | Very quick | Medium to quick | -- | -- | -- | -- | -- |
| Recommended number of control positions (settings) | 2 | 2 | 2-3 | 3-24 | -- | -- | -- | -- | -- |
| Space requirements for location and operation of control | Small | Large | Small | Medium | Small to medium | Medium to large | Large | Medium to large | Large |
| May require special design consideration to reduce lieklihood of accidental activation | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Desirable limits to control movement | -- | -- | -- | -- | Unlimited | Unlimited | $\pm 60^{o}$ | $\pm 90^{o}$ | Small [1] |
| Effectiveness of coding | Fair to good | Poor | Fair | Good | Good | Fair | Fair | Good | Poor |
| Effectiveness of visually identifying control position | Poor [2] | Poor | Fair to good | Fair to good | Fair [3] to good | Poor [4] | Poor to fair | Fair to good | Poor |
| Effectiveness of non-visually identifying control position | -- | -- | Good | Fair to good | Poor to good | Poor [4] | Poor to fair | Poor to fair | Poor to fair |
| Effectiveness of check-reading to determine control position when part of a group of like controls | Poor [2] | Poor | Good | Good | Good [3] | Poor [4] | Poor | Good | Poor |

| | TYPE OF CONTROL | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | DISCRETE ADJUSTMENT | | | | CONTINUOUS ADJUSTMENT | | | | |
| CHARACTERISTICS | Hand push button | Foot push button | Toggle switch | Rotary selector switch | Knob | Crank | Hand-wheel | Lever | Pedal |
| Effectiveness of operating control simultaneously with like controls in an array | Good | Poor | Good | Poor | Poor | Poor | Poor | Good | Poor |
| Effectiveness as part of a combined control | Good | Poor | Good | Fair | Good [5] | Poor | Good | Good | Poor |

1 Except for rotary pedals which have unlimited range.

2 Exception: when control is back-lighted and light comes on when control is activated.

3 Applicable only when control makes less than one rotation. Round knobs must also have a pointer attached.

4 Assumes control makes more than one rotation.

5 Effective primarily when mounted concentrically on one axis with other knobs.

3.5.1.4.1 Shape should be concave inward to fit the finger. When this is impractical, the surface should provide a high degree of frictional resistance to prevent slipping.

3.5.1.4.2 To indicate that the control has been activated, an audible click should be provided when the working environment is not noisy.

3.5.1.4.3 When prevention of accidental activation is imperative, provide a channel or cover guard.

3.5.2 Foot push button

3.5.2.1 Size

3.5.2.1.1 Minimum diameter: 1/2 inch

3.5.2.1.2 Maximum diameter: no limitations set by operator performance

3.5.2.2 Displacement

3.5.2.2.1 Minimum displacement for normal operation: 1/2 inch

3.5.2.2.2 Minimum displacement for operator wearing heavy boots: 1 inch

3.5.2.2.3 Maximum displacement for controls operated by ankle flexion only: 2 1/2 inches

3.5.2.2.4 Maximum displacement for controls operated by leg movements: 4 inches

3.5.2.3 Resistance

3.5.2.3.1 Minimum resistance when foot will not rest on control: 4 pounds

3.5.2.3.2 Minimum resistance when foot may rest on control: 10 pounds

3.5.2.3.3 Maximum restance for normal operation, foot resting or not resting on control: 20 pounds

3.5.2.4 General

3.5.2.4.1 Control should normally be designed for toe operation (by the ball of the foot), rather than heel operation. Where space permits, foot push buttons should be replaced by a pedal hinged at the heel. This device serves as a push button while aiding in locating and activating the control.

3.5.2.4.2 Provide "snap feel" (and audible click if possible) to indicate that the control has been activated.

3.5.3 Toggle switch

3.5.3.1 Size

3.5.3.1.1 Control tip diameter, minimum: 1/8 inch

3.5.3.1.2 Control tip diameter, maximum: 1 inch

3.5.3.1.3 Lever arm length, minimum: 1/2 inch

3.5.3.1.4 Lever arm length, maximum: 2 inches

3.5.3.2 Displacement

3.5.3.2.1 Minimum (between adjacent control positions): $30^{\circ}$

3.5.3.2.2 Maximum (total displacement): $120^{\circ}$

3.5.3.3 Resistance

3.5.3.3.1 Minimum resistance: 10 ounces

3.5.3.3.2 Maximum resistance: 40 ounces

3.5.3.4 General

3.5.3.4.1 In general, toggle switches will be vertically oriented with up for on and down for off.

3.5.3.4.2 Toggle switches will be mounted to operate horizontally only to be consistent with the orientation of the controlled function or equipment location.

3.5.3.4.3 Toggle switches are always considered discrete position controls. Small controls the same size and shape as toggle switches, but used for making continuous adjustments are classed as levers and are covered under the section pertaining to levers.

3.5.3.4.4 When inadvertent operation is considered serious, those toggle switches susceptible to activation must be guarded. This is generally done with a channel guard. When prevention of accidental activation is of primary importance a cover guard should be used.

3.5.4 Rotary selector switch

3.5.4.1 Size

3.5.4.1.1 Minimum pointer (selector) length: 1 inch

3.5.4.1.2 Maximum pointer length: No limitation set by operator performance

3.5.4.1.3 Minimum pointer width: No limitations set by operator performance

3.5.4.1.4 Maximum pointer width: 1 inch

3.5.4.1.5 Minimum pointer depth: 1/2 inch

3.5.4.1.6 Maximum pointer depth: 3 inches

3.5.4.2 Displacement

3.5.4.2.1 Minimum displacement (between adjacent detents) for visual positioning: $15^{o}$

3.5.4.2.2 Minimum displacement (between adjacent detents) for non-visual positioning: $30^{o}$

3.5.4.2.3 Maximum displacement (between adjacent detents) for facilitating operator performance: $40^{o}$

3.5.4.2.4 Maximum displacement (between adjacent detents) when special engineering requirements demand large separations: $90^{o}$

3.5.4.3 Resistance

3.5.4.3.1 Minimum: 12 ounces

3.5.4.3.2 Maximum: 48 ounces

3.5.4.4 General

3.5.4.4.1 It is undesirable for a rotary selector switch to have more than 24 positions. However, when more positions must be made available, the minimum separation between adjacent positions should be 1/4 inch at the index marks.

3.5.4.4.2 Whenever possible, control positions should not be $180^{o}$ from each other in order to reduce errors in setting and in reading the wrong end of the moving pointer.

3.5.4.4.3 Whenever feasible, stops should be placed at the beginning and end of the range of central positions. This will facilitate blind-positioning by enabling the operator to count the number of settings (by the feel of the detent action or by the sound of the click) from a starting position.

3.5.4.4.4 The pointer knob should be a bar type with a tapered tip. An exception to this is the application of shape coding to the pointer knobs. Shape coding is recommended when a group of rotary controls, used for widely different functions, are placed on one panel and control confusion is likely.

3.5.4.4.5 The position of the pointer knob in relation to the scale shall be such as to minimize parallax.

3.5.4.4.6 A moving pointer-knob on a fixed scale should be used unless complete justification exists for the use of a moving scale with a fixed index.

3.5.5 Knobs

3.5.5.1 Size

Within the ranges recommended below, knob size is relatively unimportant provided the control-display ratio is optimum, the resistance low and the knob easily grasped. When panel space is limited, the use of minimum values for knob size will not degrade performance provided the resistance is very low.

3.5.5.1.1 Minimum depth (finger grasp knob): 1/2 inch

3.5.5.1.2 Maximum depth (fingertip grasp knob): none

3.5.5.1.3 Minimum diameter (fingertip grasp knob): 3/8 inch (Not recommended for general use. Practical minimum: 1 inch)

3.5.5.1.4 Maximum diameter (fingertip grasp knob): 4 inches

3.5.5.1.5 Minimum diameter (palm grasp knob): 1 1/2 inches

3.5.5.1.6 Maximum diameter (Palm grasp knob): 3 inches

3.5.5.1.7 Minimum diameter (thumb and finger encircled): 1 inch

3.5.5.1.8 Maximum diameter (thumb and finger encircled): 3 inches

3.5.5.2 Displacement

Displacement should be determined by the desired control-display ratio. (See section 3.6)

3.5.5.3 Resistance

3.5.5.3.1 Minimum: No practical limit set by operator performance. Jarring, vibration or other conditions may determine minimum resistance limit.

3.5.5.3.2 Maximum for fingertip operation with small (1 inch diameter) knobs: 4 1/2 inch-ounces

3.5.5.3.3 Maximum for fingertip operation with larger knobs (above 1 inch diameter): 6 inch-ounces

3.5.5.4 General

3.5.5.4.1 Knobs lend themselves well to shape coding. For coding methods the designer should consult the Human Factors Section of the project.

3.5.5.4.2 A moving knob with a fixed scale is preferred for most tasks; however, if so demanded, a moving scale with a fixed index may be used.

3.5.6 Cranks

3.5.6.1 Size

3.5.6.1.1 Minimum radius: 1/2 inch

3.5.6.1.2 Maximum radius (heavy load): 20 inches

3.5.6.1.3 Maximum radius (minimum load and high rate-up to 275 rpm): 4 1/2 inches

3.5.6.2 Displacement

Displacement should be determined by the desired control-display ratio. (See section 3.6)

3.5.6.3 Resistance

3.5.6.3.1 Small cranks (less than 3 1/2 inch radius)

3.5.6.3.1.1 Minimum for high-speed operation (rapid, steady turning): 2 pounds

3.5.6.3.1.2 Maximum for high-speed operation (rapid, steady turning): 5 pounds

3.5.6.3.2 Large cranks (5-8 inch radius)

3.5.6.3.2.1 Minimum for high-speed operation (rapid, steady turning): 5 pounds

3.5.6.3.2.2 Maximum for high-speed operation (rapid, steady turning): 10 pounds

3.5.6.3.2.3 Minimum for making precise settings (adjusting between 1/2-1 rotation): 2 1/2 pounds

3.5.6.3.2.4 Maximum for making precise settings (adjusting between 1/2-1 rotation): 8 pounds

3.5.6.4 General

3.5.6.4.1 The grip handle should be designed so that it turns freely around its shaft

3.5.7 Handwheel

Handwheels are designed for two-hand operation. Rotary controls small enough to be grasped by one hand are classified as knobs and are covered in section 3.5.5.

3.5.7.1 Size

3.5.7.1.1 Minimum handwheel diameter: 7 inches

3.5.7.1.2 Maximum handwheel diameter for seated operator with hands at each end of the diameter (most desirable position for making precise setting): 21 inches

3.5.7.1.3 Maximum handwheel diameter if operator is not required to hold wheel at opposite ends of its diameter: No limitations set by operator performance

3.5.7.1.4 Minimum cross-sectional diameter or rim: 3/4 inch

3.5.7.1.5 Maximum cross-sectional diameter or rim: 2 inches

3.5.7.2 Displacement

Displacement should be determined by the desired control-display ratio (see section 3.6) and by the height of control above the standing surface.

3.5.7.2.1 A maximum displacement of 90°-120° is desirable, providing the optimum control-display ratio is not hindered. Larger displacements require the hands to shift positions on the control.

3.5.7.3 Resistance

3.5.7.3.1 Minimum: 5 pounds

3.5.7.3.2 Maximum for one hand operation: 30 pounds

3.5.7.3.3 Maximum for two hand operation: 50 pounds

Note: A seated operator can apply most force (torque) to a handwheel when it is located 16-19 inches forward of the seat reference point

3.5.7.4 General

3.5.7.4.1 Identation or knurling should be built into the handwheel to aid in holding it

3.5.7.4.2 For many rotations, a "spinner" handle may be attached to the handwheel.

3.5.7.4.3 When the maximum displacement is less than 120°, only the two sections of the handwheel which the operator grasps may be provided. These parts are usually the chords of arcs, each approximately 6 inches long, across from one another. (Eliminating the rest of the control increases the visual and pedal areas.)

3.5.8 Lever

3.5.8.1 Size

Length should be determined by the mechanical advantage which is needed. In making large fore-aft movements, a long lever is usually more desirable than a short one because movements of the long lever are more nearly linear.

3.5.8.2 Displacement

3.5.8.2.1 Minimum: No minimum established

3.5.8.2.2 Maximum for fore-aft movement: 14 inches

3.5.8.2.3 Maximum for lateral movement: 38 inches

3.5.8.3 Resistance

3.5.8.3.1 Minimum for lever handle grasped by hand (rather than finger): 2 pounds

3.5.8.3.2 Maximum

3.5.8.3.2.1 Push-pull (fore-aft) movements for one hand operation with control along median plane of body, 10 inches forward from seat reference point: 30 pounds.

3.5.8.3.2.2 Push-pull (fore-aft) movements for one hand operation with control along median plane of body, 16-24 inches forward from seat reference point: 50 pounds

Note: The right hand can apply slightly more force than the left, but not enough to be considered significant.

3.5.8.3.2.3 Push-pull (fore-aft) movements for two hand operation with control along median plane of body, 10-19 inches forward from seat reference point: twice as much as for one hand operation. (Beyond this two-hand operation becomes less effective)

3.5.8.3.2.4 Right-left (lateral) movements for one hand operation with control 10-19 inches forward of seat reference point: 20 pounds

3.5.8.3.2.5 Right-left (lateral) movements for two hand operation with control 10-19 inches forward of seat reference point: 30 pounds.

3.5.8.4 General

3.5.8.4.1 When a group of levers are placed in proximity to each other, and are not readily discriminable from each other, the lever handles should be coded.

3.5.8.4.2 When the handle is spherical, it shall meet the following specifications:

3.5.8.4.2.1 Minimum diameter for finger grasp: 1/2 inch

3.5.8.4.2.2 Minimum diameter for hand grasp: 1 1/2 inches

3.5.8.4.2.3 Maximum diameter: 3 inches

3.5.8.4.3 In making fine or continuous adjustments, support should be provided for the body part being used.

3.5.8.4.3.1 Elbow-for large hand movements

3.5.8.4.3.2 Forearm-for small hand movements

3.5.8.4.3.3 Wrist-for finger movements

3.5.9 Pedals

3.5.9.1 Size

3.5.9.1.1 Minimum: 1 x 3 inches

3.5.9.1.2 Maximum: This is determined by space available and danger of accidental activation. (Should be large enough that the entire width of the foot can rest on it and apply force to it.)

3.5.9.2 Displacement

3.5.9.2.1 Minimum displacement for normal operation: 1/2 inch

3.5.9.2.2 Minimum displacement for operator wearing heavy boots: 1 inch

3.5.9.2.3 Maximum displacement for ankle flexion only: 2 1/2 inches

3.5.9.2.4 Maximum displacement for leg movement: 7 inches

3.5.9.3 Resistance

3.5.9.3.1 Minimum resistance if foot will not rest on control: 4 pounds

3.5.9.3.2 Minimum resistance if foot may rest on control: 10 pounds

3.5.9.3.3 Maximum resistance for ankle flexion only: 20 pounds

3.5.9.3.4 Maximum resistance for leg movement: 180 pounds

3.5.9.4 General

3.5.9.4.1 The pedal should return to its null position when force is removed.

Note: Control labeling is covered in section 5 of this exhibit.

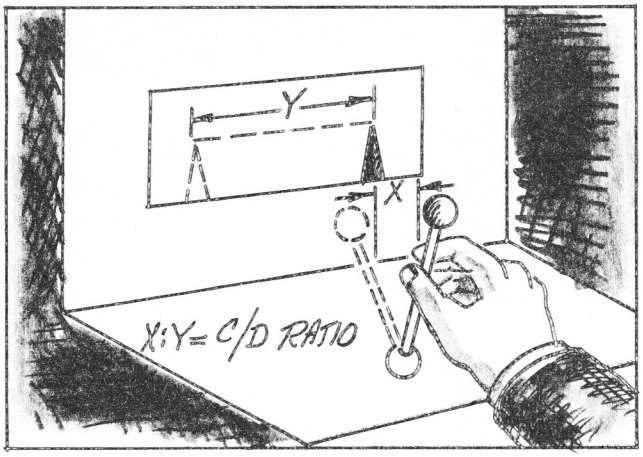
3.6 Control - display ratio

3.6.1 General

3.6.1.1 Control-display (C/D) is the ratio of distance of movement of the control to that of the moving element of the display (pointer, cursor, etc.).

3.6.1.2 For linear and near linear controls (e.g., levers) which affect linear displays, the C/D ratio is usually defined as the linear distance of control displacement to distance of resulting display movement. Control displacement should be measured from the point where the operator's hand grasps the control.

3.6.1.3 For small rotary controls (e.g., knobs) which affect linear displays, the C/D ratio is usually defined as the number of control rotations to distance of resulting display movement.




3.6.2 Optimizing C/D ratio

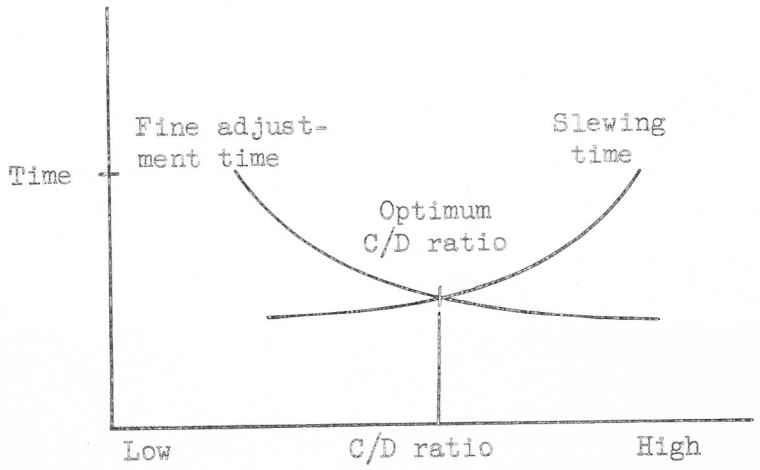
3.6.2.1 In positioning a continuous adjustment (non-detent) control, the operator makes two types of movement:

3.6.2.1.1 A slewing movement (also referred to as "travel", "gross adjusting movement", and "primary movement") in which he rapidly moves his control close to the final desired position. An increase in the C/D ratio will increase slewing time because of the longer movements required. However, for linear controls, slewing time is only slightly greater for long movements than for short ones.

3.6.2.1.2 A fine adjusting movement (also referred to as "adjusting movement" or secondary movement") in which he places his control precisely in the desired position. Fine adjusting time is reduced either by increasing the C/D ratio or by easing the tolerance requirements (i.e., increasing the maximum acceptable error in positioning the control).

3.6.2.2 The optimum C/D ratio is that which minimizes total time (slewing + fine adjusting) required to make the desired control movement.

3.6.2.3 Typical C/D curves



3.6.3 Primary factors affecting the C/D ratio

3.6.3.1 Display size: With tolerance kept constant, changing the size of the display may change total adjustment time.

3.6.3.2 Tolerance: Fine adjusting time is reduced directly by easing the tolerance requirements. Slewing time is probably also reduced because the operator tends to move his control into position more slowly when he knows that it will have to be positioned precisely. Changing tolerance may change the optimum C/D ratio.

3.6.3.3 Viewing distance: Research data suggests that viewing distance does affect performance and that it might also change the optimum C/D ratio, although no definite relationships have been established as yet.

3.6.3.4 Time delays: The type and extent of any time delay in the system may affect the optimum C/D ratio. For exponentially shaped time delays occurring between the control movement and the resulting display response, within reasonable limits, the longer the time delay, the smaller will be the optimum C/D ratio.

3.6.4 Recommendations

In most applied problems, the designer will be unable to determine the optimum C/D ratio from available research. Hence, whenever possible he should determine the optimum ratio experimentally keeping in mind that it may be affected by display size, tolerance, viewing distance and time delays.

3.7 Direction-of-movement relationships

The direction in which a control should move is discussed in this part. In order to be correct, the direction of movement of the control must be related appropriately to the change which it induces in its associated display, equipment component and/or the system as a whole. Correct direction-of-movement relationships will improve system performance in:

a. Precision of control adjustment

b. Correctness of initial control movements (i.e., reducing movement in the wrong direction, called reversal error).

c. Speed of reaction or decision time

d. Speed of control adjustment

e. Speed of learning

These improvements are relatively unimportant if the operator has a simple repetitive task. Their importance increases directly with:

a. Task complexity

b. Discontinuity or number of interruptions in the control sequence.

c. Degree of stress or anxiety

The direction-of-movement relationships recommended here are made to satisfy one or more of three basic requirements:

a. Natural relationships (control movement habit patterns which are consistent from person to person without special training or instructions)

b. Existing design practices

c. Standardization and consistency.

3.7.1 General rules

3.7.1.1 The direction-of-movement of the control must be considered in relation to all of the following factors:

a. Operator position: His location and orientation relative to the control.

b. Display position and response: The position of the display relative to the control; the nature and direction of the display response.

c. Equipment component response: The change exhibited by an equipment component as a result of the control movement either in terms of motion for moving components or in terms of power for stationary components.

3.7.1.2 Control movements should be consistent for all the equipment which one operator uses.

3.7.1.3 The direction of movement of controls and displays should be related to the purpose underlying each control movement rather than to any particular mechanism or method of actuation used to perform the desired function (i.e., to raise voltage, upward or clockwise movement; to lower voltage, downward or counter-clockwise movement).

3.7.2 Specific recommendations

3.7.2.1 When a display has a moving pointer and a stationary dial, a clockwise rotation of the rotary control should result in a clockwise rotation of the pointer.

3.7.2.2 A rotary control should be on the concave side of a rotary display when the display movement traverses less than a full circle.

3.7.2.3 When a rotary control and a linear display are in the same plane, the part of the control adjacent to the display should move in the same direction as the moving part of the display.

3.7.2.4 A rotary control should not be placed above any display or to the left of a vertical display. This avoids conflict between principle 3.7.2.3 above and the principle that a clockwise control movement should result in either an upward or rightward pointer movement.

3.7.2.5 A forward control movement is generally associated with "increase" or "raise" as opposed to "decrease" or "lower".

3.7.2.6 When there is no direct linkage between control and display, a linear control may be used with a rotary display.

3.7.2.7 When there is a direct linkage between control and display:

3.7.2.7.1 If the indicator moves through an arc of more than 180°, a rotary control should be used.

3.7.2.7.2 If the indicator moves through an arc of less than 180°, a linear control may be used provided the path of the control movement parallels the average path of the indicator movement and the indicator and control move in the same relative direction.

3.7.2.8 The direction of linear control movements for on-off (or increase-decrease) controls such as levers and toggle switches is determined by the location of the panel on which these controls are mounted.

3.7.2.8.1 For controls mounted on vertical panels: "On" or "increase" should be an upward movement, "off" or "decrease" a downward movement.

3.7.2.8.2 For controls mounted on horizontal overhead panels: "On" or "increase" should be a forward movement, "off" or "decrease" a rearward movement.

3.7.2.8.3 For controls mounted on upward facing horizontal panels: "On" or "increase" should be a forward movement, "off" or "decrease" a rearward movement.

3.7.2.8.4 For controls mounted on sloping panels: There may be no sharply defined divisions between up-down and forward-rearward control movements. When panels are below eye-level, this is unimportant because forward and upward movements both require the operator to apply force in the same general direction. However, for panels above eye-level a forward movement is opposite that of an upward movement; therefore to avoid ambiguous situations:

3.7.2.8.4.1 For overhead panels tilted less than 45° from the vertical: Controls should be actuated as if the panel were vertical ("on" or "increase" should be an upward movement).

3.7.2.8.4.2 For overhead panels tilted more than 45° from the vertical: Controls should be actuated as if the panel were horizontal ("on" or "increase" should be a forward movement).

Note: Operators cannot make accurate estimates of tilt angles; therefore, overhead panels should not be placed at a 45° tilt. The best place to break directions is at an actual break in the panel. If no such breaks occur, panels should be either less than 30° or greater than 60° from the vertical.

3.7.2.8.5 When surfaces at slight angles to each other are joined to form a continuous control panel (e.g., a console on which control panels are arranged radially about the operator), control movement should be consistent throughout the panel. All movement relationships should be the same as those established for the central panel.

3.7.2.8.6 When on-off controls are integral parts of an equipment unit which might be placed in various positions relative to the operator (e.g., in front of the operator, overhead, on either side), controls and labels should be constructed so that they can be rotated through 90°. In this way the control can always be oriented for the proper direction-of-movement relationship.

3.7.2.9 Valve controls should operate and be labeled according to the end purpose which they serve (e.g., "raise" or "drain"). In this way, direction-of-movement relationships for controls and displays can be consistent both with each other and with other control-display movements in the system.

3.7.2.10 Direction-of-movement relationships do not apply to simple on-off or reset controls (push-buttons) which are spring loaded, move in only one direction and are activated by applying force in that direction. These controls may be mounted anywhere within the limiting dimensions. Their exact location should be determined primarily by the direction in which the operator can apply force most effectively.

3.8 Check list for a good control

Listed below are the prime characteristics of a good control. In general they are a summary of the more salient principles listed in the foregoing sections and should serve as a check list for the designer.

3.8.1 Control movement should be in the "expected" direction; that is, increases should be caused by movements to the right, upward or clockwise.

3.8.2 Control movements and location should be parallel to the axis of the display motion which they affect.

3.8.3 Controls should be selected so that no one limb is overburdened.

3.8.4 Controls should be designed and located so that they are not susceptible to accidental activation.

3.8.5 Round knobs should be used for controls requiring smooth continuous movement. Bar or pointer type knobs should be used for detent-type switching.

3.8.6 Control actions should be positive without being sticky or stiff.

3.8.7 Adjustment-type knobs for electronic equipment should be no more than 2 inches in diameter and should be used only for very light torques.

## 4. CONTROL PANEL LAYOUT

### 4.1 General

This part deals with the placement of individual controls and displays within the general spaces allotted to them. Four major factors will be considered:

a. Priority: assigning the most important controls and displays to the optimum area

b. Grouping: organizing controls and displays into logical units

c. Association: establishing a correct and consistent relation (correspondence) between each control and its related display

d. Spacing: providing proper separation between controls

The rules presented in this part should aid the designer in establishing an optimum arrangement of controls and displays. After this layout has been established, it should, as far as possible, be used throughout the system and in all subsequent models of the same system. These rules are general ones and cannot be expected to apply explicitly to all cases. In the event that two rules conflict with each other, the designer must determine a compromise based primarily upon the needs (or specific requirements) of ths system being designed.

4.2 Establishing priority positions

4.2.1 Procedures

Analyze how the control or display is used by the operator and what its ultimate effect is upon system performance. Its priority may be measured in various ways. The most common ways involve determining one or more of the following:

a. The frequency and extent of use of the control or display.

b. The accuracy and/or speed with which the display must be read or the control positioned.

c. The decrease in system performance and/or safety resulting from an error or delay in using the control or display.

d. The ease of manipulating certain controls (in terms of force which can be applied, precision and speed of adjustment) in various locations.

4.2.2 Rules

4.2.2.1 Primary (highest priority) controls and displays should be placed in the optimum spaces (as defined in Section 6 of this exhibit)

4.2.2.2 Emergency controls and displays should be placed in readily accessible positions. Emergency controls and displays will not usually be located in the optimum areas in preference to primary controls and displays. In some systems, however, the nature of an emergency is so critical that emergency equipment should be given top priority in location.

4.2.2.3 Secondary controls and displays (less important than primary ones but still used periodically during normal operations) should be placed within the limiting areas but not necessarily within the optimum areas. Their exact location should be determined primarily by proper grouping and associations (as described in Sections 4.3 and 4.4). Standardization is essential whenever a large number of such controls and displays must be used by one operator.

4.2.2.4 Set-up and calibration controls (which are used infrequently before the operator begins his primary tasks or during any convenient slack period) and their associated displays should normally be given lowest priority in assigning locations. They may be located outside of the operator's normal workplace unless they are used with other controls or displays.

4.2.2.5 The shared use of controls and/or displays by more than one operator requires special consideration:

4.2.2.5.1 If primary controls or displays must be used by more than one operator, duplicate sets should be provided wherever there is adequate space; otherwise, controls or displays should be centered between the operators.

4.2.2.5.2 If secondary controls or displays must be used by two operators, they should be placed between the operators. If they are of equal importance to two operators, they should be centered between them; if they are more important to one operator, they should be nearer him.

4.2.2.5.3 Whenever direction-of-movement relationships are important and controls or displays must be shared by more than one operator, the operators shall all face in the same direction.

4.2.2.5.4 When direction-of-movement relationships are unimportant operators need not all face in the same direction.

## 4.3 Grouping controls and displays

### 4.3.1 Procedures

There are two general ways of grouping-both should be followed whenever possible:

4.3.1.1 Functional grouping

Group together all controls or displays which are:

a. Identical in function (e.g., circuit breakers)

b. Used together in a specific task (e.g., arming switches)

c. Related to one system component (e.g., all controls and displays pertaining to target change)

4.3.1.2 Sequential grouping

Group together and arrange in normal order of use:

a. Controls which are operated in sequence (e.g., switches used in starting system)

b. Displays which are observed in sequence (e.g., meters on an electrical distribution panel)

4.3.2 Rules

4.3.2.1 Displays should be grouped so as to facilitate check reading.

4.3.2.2 When displays are used sequentially:

4.3.2.2.1 Displays should be aligned so that they are viewed in the following sequence:

a. Horizontally from left to right

b. Vertically from top to bottom

c. Rows: from top to bottom row and from left to right within a row.

4.3.2.2.2 They should be grouped as close together as possible.

4.3.2.2.3 The direction in which they are aligned (horizontally, vertically or in rows) should be determined primarily by the correct control-display association (as covered in section 4.4).

4.3.2.2.4 Unless important control-display associations are violated, the displays should be aligned horizontally provided they do not extend beyond the visual area. If a large number of displays must be viewed in sequence, they should be arranged in rows rather than columns.

4.3.2.3 When controls are used sequentially by the same hand, they should be arranged so that the operator moves his arm horizontally from one to the next (provided that control-display and/or control-component locations do not result in violations of associations, as covered in section 4.4).

4.3.2.4 When controls which are used sequentially cannot be aligned horizontally, they should be arranged in some other systematic manner, such as vertically from top to bottom.

4.3.2.5 When concentric (ganged) knobs are used sequentially, the front (smallest) knob should be used first, the back (largest) knob last.

Caution: Grouping of controls should not interfere with the division of major tasks among the various limbs of the operator.

4.4 Associating controls and displays

4.4.1 Purposes

Whenever an operator must use a large number of controls and/or displays, their location and arrangement should aid him in determining:

a. Which controls are used with which displays.

b. Which equipment component each control affects.

c. Which equipment component each display describes.

4.4.2 Rules

4.4.2.1 When a control is always associated with a specific display, the control should be located so that the operator's hand does not block the display from sight.

4.4.2.1.1 Controls operated by the right hand should be located below or to the right of their associated displays.

4.4.2.1.2 Controls operated by the left hand should be located below their associated displays. They may also be located to the left of their displays provided that direction-of-movement relations (see section 3.7) are not violated.

4.4.2.2 When a large number of displays are on the same panel, they should normally be arranged in either of the following two ways:

4.4.2.2.1 Each display directly above its associated control. All control-display combinations must be located close together so that wrong associations are not made (e.g., controls should be associated with the displays above them, not below them).

4.4.2.2.2 All displays in the upper portion and all controls in the lower protion of the panel. Each control occupies the same relative position as its associated display.

Note: Any rearrangement which changes the relative positions among controls or among displays (such as that resulting from reversing the positions of two controls) will seriously degrade operator performance. Such a change can result in a four-fold (or more) increase in both time and errors in selecting the proper control for a given display, either for skilled or unskilled operators.

4.4.2.3 When concentric (ganged) knobs must be associated with displays, the displays should be arranged in a row from left to right: the front (small) knob controlling the left display, the middle knob the middle display, the back knob the right display.

4.4.2.4 When rows of displays must be associated with columns of controls, and vice-versa, left should correspond with top, and right with bottom. However, these arrangements should be avoided, if possible.

4.4.2.5 When two or more rows of displays must be associated with one row of controls, and vice-versa, the left to right top to bottom rule should be applied.

4.4.2.6 When all controls are on a control panel and their associated displays are on a display panel, good control-display associations can still be maintained:

4.4.2.6.1 When both panels are mounted at approximately the same angle relative to the operator, the controls on one panel should occupy positions corresponding to those of their associated displays on the other panel.

4.4.2.6.2 The two panels should never face each other.

4.4.2.6.3 When one panel is at (or near) the horizontal and the other panel is at (or near) the vertical, the controls on one panel should occupy positions corresponding to those of their associated displays on the other panel.

4.5 Spacing between controls

4.5.1 Factors affecting spacing

In determining the proper spacing between controls within a given area, the following factors should be considered:

a. Simultaneous use of controls

b. Sequential use of controls

c. Body part being used

d. Size of control and amount of movement (displacement or rotation).

e. Need for "blind reaching" (i.e., being able to reach for and grasp the control without seeing it).

f. Effects upon system performance of inadvertently using the wrong control.

g. Encumbrances - gloves, boots, etc.

4.5.2 Rules

4.5.2.1 Foot controls should normally be spaced further apart than hand controls.

4.5.2.2 When blind reaching may be required, there should be greater separation between controls than when the operator looks at the control.

4.5.2.3 When the effect of inadvertently using a wrong control (among several) is serious, the several controls should be widely separated.

4.5.3 Recommended distances between controls

The specific distances separating controls is so much a function of the task being performed (and the space available) that rigid adherence to a single set of specifications is inadvisable. Minimum and desirable values are offered as guides.

Minimum: The least acceptable distance between adjacent controls when the operator is in a stationary workplace with good environmental conditions and when controls are placed within the optimum manual (or pedal) areas.

Desirable: The preferred distance between adjacent controls which either are operated intermittently or are in a moving vehicle where the operator and/or control is subjected to jolting, vibration, etc.

Table 4 presents recommended separations for various conditions of use. Unless stated otherwise, separations are measured between adjacent edges of two controls, regardless of control size.

Caution: If the operator is wearing gloves, heavy shoes, or any other type of clothing which interferes with his movements, the specified separation between controls may have to be increased.

To conserve limited panel space, or aid in sequential operations, two or three knobs may be mounted on concentric shafts. Chances of accidental operation are increased if either the knob diameters or thicknesses are too large, too small, or differ by too small an amount. The chart below states recommended dimensions for concentrically mounted knobs when accidental operation must be strongly guarded against:

| | Diameter | Thickness |
|---|---|---|
| Front (small) knob | 1/2" | 3/4" |
| Middle knob | 1 3/4" | 3/4" |
| Back (large) knob | 3 " | 1/4" |

4.6 Check list for good panel layout

The following list of desirable characteristics may be used as a check list for a well designed instrument panel:

4.6.1 Any given instrument should be easy to find and identify.

4.6.2 The most important and frequently used instruments should have the most favorable position with reference to the normal line of sight.

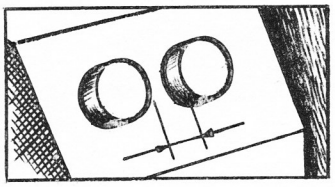
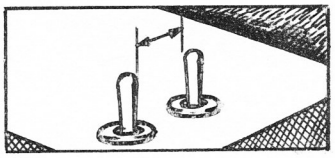
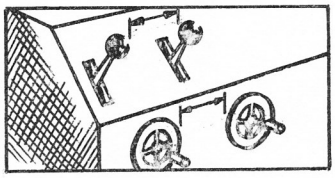
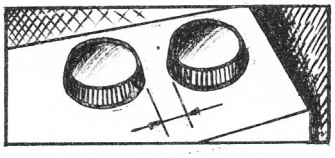
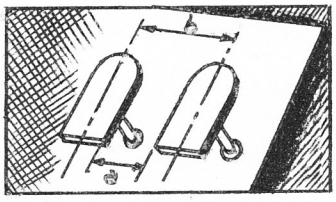
4.6.3 Arrangement of the primary instruments should be consistent with other panels which the same operators may use in other crew stations (standardized arrangement)

4.6.4 The instruments should be arranged in relation to one another to conform with the location of equipments to which they refer.

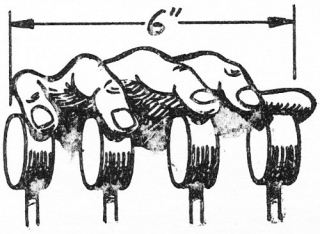
4.6.5 The manner of indication should be consistent for different instruments (e.g., all pointers on circular scales move clockwise for increase).

4.6.6 All instruments should be readable from the normal head position of the operator, allowing for normal head rotation and restrictions imposed by helmets or other headgear. There should be no obstruction by other equipment, or occluding of dials because of oblique angle of view.

TABLE 4 -- RECOMMENDED SEPARATION BETWEEN CONTROLS

| CONTROL | TYPE OF USE | MEASURE OF SEPARATION | RECOMMENDED SEPARATION Minimum | Desirable |
|---|---|---|---|---|
| Push button | One finger--randomly* |  | 1/2" | 2" |
| | One finger--sequentially | | 1/4" | 1" |
| | Different fingers--randomly or sequentially | | 1/2" | 1/2" |
| Toggle switch | One finger--randomly* |  | 3/4" | 2" |
| | One finger--sequentially | | 1/2" | 1" |
| | Different fingers--randomly or sequentially | | 5/8" | 3/4" |
| Cranks and levers** | One hand--randomly* |  | 2" | 4" |
| | Two hands--simultaneously | | 3" | 5" |
| Knobs | One hand--randomly* |  | 1" | 2" |
| | Two hands--simultaneously | | 3" | 5" |
| Pedals*** | One foot--randomly |  | a = 4" | 6" |
| | | | b = 8" | 10" |
| | One foot--sequentially | | a = 2" | 4" |
| | | | b = 6" | 8" |

*When finger - or hand-operated controls are used randomly and are "blind positioned," they should be separated by at least 5 inches when mounted in the optimum manual area. This separation should be progressively increased to 12 inches as the location of the control approaches the periphery of the limiting manual dimensions.




**When a group of levers are used simultaneously by the same hand, their maximum separation should be 6 inches or less.

***Either dimension a or dimension b should be met, preferably a.

4.6.7 If control knobs are adjacent to the instrument they control (as is usually desirable) they should be so located that the hand normally used for setting will not obscure the indicator.

4.6.8 Instruments used most frequently should be grouped together to minimize eye movement distance in shifting from one instrument to another.

Note: Control panel labeling is covered in section 5 of this exhibit.

5. CONTROL PANEL IDENTIFICATION

5.1 General

It is important that the operator have as many cues as possible to identify controls and displays. In addition to size, shape and color coding and positioning of the control or display, identification may be assisted by control and indicator labeling. The purpose of this section is to provide a guide to the designer when confronted with the problem of control panel identification by outlining various acceptable identification principles and exhibiting suggested methods of implementing these principles.

5.2 Control and display labeling

5.2.1 Label in terms of what is being indicated rather than the name of the indicator (voltage not voltmeter).

5.2.2 Label each control and each display as to function

5.2.3 Labels should appear either on or immediately adjacent to (preferably above) the controls and displays to be identified and shall be so located as to preclude association of a label with the wrong control or display.

5.2.4 The location of labels in relation to controls and displays shall be consistent on all system equipment.

5.2.5 Labels shall be brief. Although the nomenclature should clearly indicate the function being displayed or controlled, highly similar names shall be avoided. Abbreviations, where required, shall be common and meaningful.

5.2.6 Lettering on panels shall be of sufficient contrast to the background to be immediately identifiable and visible.

5.2.7 In addition to labeling control functions, it is equally important to label each control position properly and to show the direction of rotation of controls (use double ended arrows properly labeled as to increase or decrease, fast or slow, etc.)

5.2.8 Abstract symbols (squares, stars, etc.) should not be used as labels. Common meaningful symbols such as the per cent sign, plus sign, etc., are acceptable.

5.3 Identification of control-display grouping

5.3.1 Functional grouping

5.3.1.1 Whenever it is desired to set apart, for purposes of ready identification, distinct, non-critical functional areas (those not associated with emergency controls) these areas shall be outlined with engraved or painted lines of maximum contrast to their backgrounds.

5.3.1.1.1 Lines 1/16 inch wide shall be used to distinguish primary functional grouping.

5.3.1.1.2 Lines 1/32 inch wide shall be used to distinguish secondary functional grouping.

5.3.1.2 Functional areas of emergency or extremely critical operations will be set apart by a 1/8 inch red border.

5.3.1.3 When it is desirable to label a functional area, it is recommended that the outline be broken to include the label.

5.3.1.4 The outlines should contain no square corners. The use of connecting radii will do much to enhance the value of outlines.

5.3.1.5 Where panel layout prohibits the use of an outline around the entire functional group, it is permissable to use partial outlines as long as the grouping remains apparent to the operator.

5.3.2 Sequential grouping

Where the operator must monitor and/or perform a sequence of operations, it is desirable that the panel layout take the form of a simplified block diagram which is analogous to the actual order of observable events. The panel layout shall present as much information concerning the status of components operating within the sequence as warranted by mission requirements. If order cannot be indicated by position, links between events shall be schematized by lines painted or engraved on the panel.

5.3.2.1 Lines 1/8 inch wide shall be used to distinguish primary flow lines.

5.3.2.2 Lines 1/16 inch wide shall be used to distinguish secondary flow lines.

5.4 Legibility standards for letters and numerals

The following standards shall apply for all illuminated and non-illuminated legends:

5.4.1 Style of legend: Capital letters shall be used. Numerals and letters shall comply with the forms specified in AND 10400.

5.4.2 Size of legend: Numerals and letters shall comply with the following size requirements for normal viewing distances (28 - 30 inches):

| | Minor<br>General Status and Instruction Markings | Major<br>Emergency Markings |
|---|---|---|
| Height | .125 inch | .20 inch |
| Width | 3/5 height | 3/5 height |
| Stroke width | 1/6 to 1/8 height | 1/6 to 1/8 height |

Note: The height to width ratio of numerals for counter displays should be 1:1 rather than 5:3 as recommended for other markings.

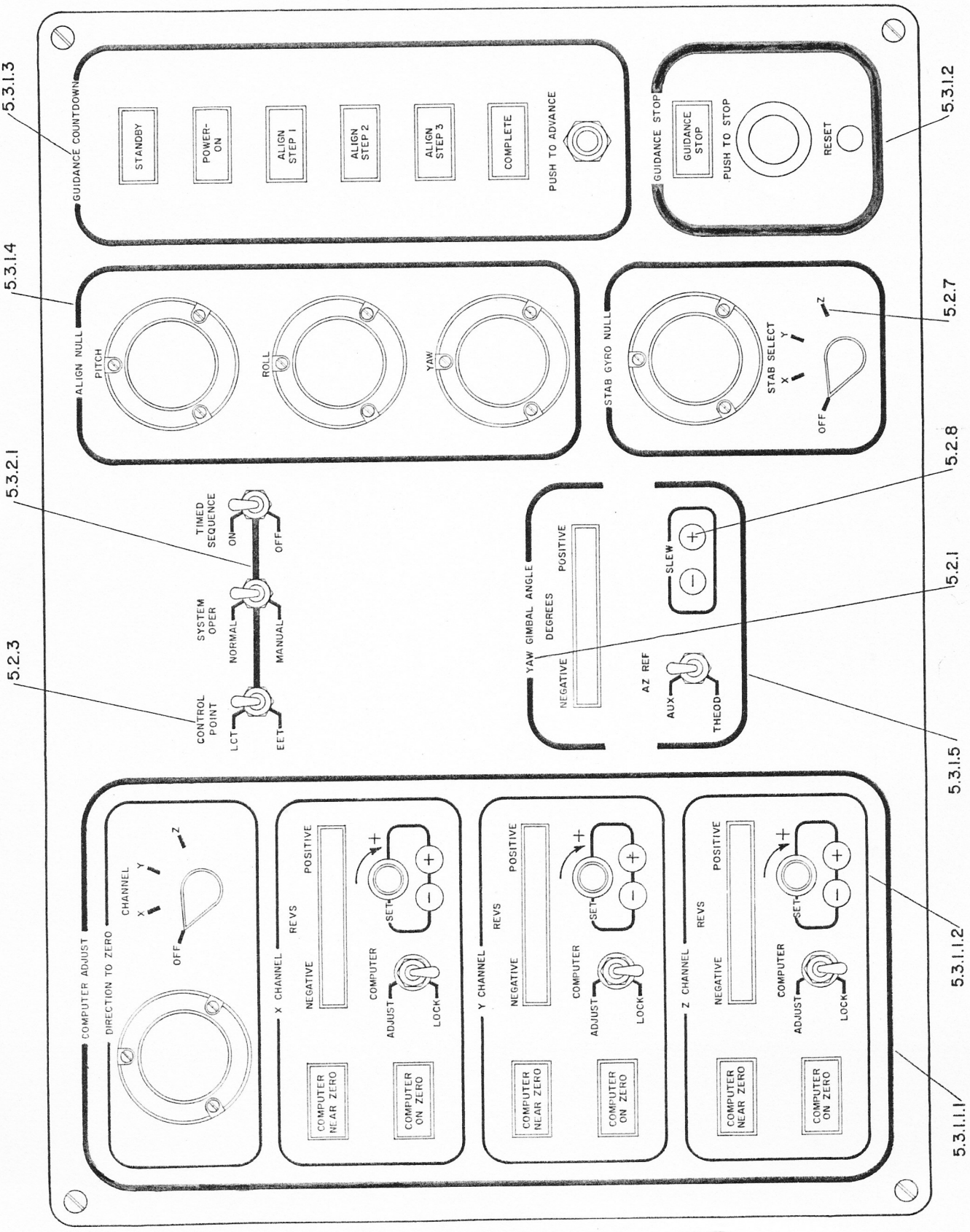
Drawing A following this section attempts to portray recommendations relative to labeling and outlining set forth in this section. The numbers indicated on the drawing refer to the applicable paragraph number within this section dealing with the labeling or outlining principle. It should be noted, however, that these are suggested principles that may be varied to meet project requirements, equipment configuration, etc., but that have been tried, proven and acceptable on prior projects.

6. WORKSPACE LAYOUT

6.1 General

Proper workplace layout requires that consideration be given to various workplace dimensions. Controls and displays should be located with due regard to the operator's size, his position (seated or standing), the directions in which he can most easily look, and the spaces in which he can best manipulate controls. Consideration should also be given to special influences such as protective clothing and interference by crew members. The location, size, etc. of equipment should be such that the equipment will be easily operated and maintained by at least the 5th to 95th percentile group of the Air Force population. Dimensions given in this section are applicable to equipment suitability for 90% of the population.

DRAWING A-SUGGESTED METHODS OF LABELING AND OUTLINING FOR CONTROL PANELS.



6.2 Standing operations

6.2.1 Ideally, visual displays on vertical panels shall be mounted in an area no higher than 70 inches and no lower than 40 inches above the standing surface. Precise reading indicators and important controls should be placed in an area no higher than 64 inches and no lower than 48 inches above the standing surface.

6.2.2 Insofar as possible, controls shall be mounted on vertical panels in an area no higher than 70 inches and no lower than 30 inches above the standing surface. The preferred area for precision controls or those operated frequently is between 40 to 55 inches from the standing service. (Since standing operators are normally free to move around, there are no limiting dimensions for panel width.)

6.2.3 Cabinets of the floor to ceiling rack type are satisfactory for most purposes. However, where cabinets containing chassis requiring the full depth of the rack also contain separate display-control panels that do not require this depth, the upper area containing the display-control panel (s) may be set back 10 inches in order to increase useful panel area and facilitate operation. The following specifications shall apply:

6.2.3.1 The sloped portion of the cabinet face shall approximate $45^{\circ}$ from the vertical.

6.2.3.2 The set back (i.e., beginning of sloped surface) shall begin at a point 35 inches above the standing surface.

6.2.3.3 The upper panel extending from a point 45 inches from the standing surface should, if possible, be sloped $10^{\circ}$ from the vertical.

6.3 Seated operations

6.3.1 When continuous monitoring or control is required of a seated operator, controls and displays shall be mounted on a sloped console surface.

6.3.2 For normal seated operations the slope of the control-display panel surface shall begin at 30 inches from the floor with the overall console height not exceeding 48 inches (This will allow the operators direct line of sight to extend beyond the console.)

6.3.2.1 On consoles having a single sloped panel surface the angle of the slope shall be $30^{\circ}$ from the vertical.

6.3.2.2 On consoles having two or more sloped panel surfaces the lower forward panel shall be inclined $60^{\circ}$ from the vertical.

6.3.3 If the operators direct line of sight is not required to extend beyond the console, the overall console height may extend to, but not exceed, 65 inches from the floor. In such situations the upper panel surface (s) shall be inclined from the vertical toward the operator and the console may have three panel surfaces.

6.3.3.1 The slope of the upper panel surface shall be $10^{o}$ from the vertical to be inclined toward the operator.

6.3.3.2 Only the least important visual displays shall be located on the upper panel surface.

6.3.3.3 No controls shall be located on the upper panel surface.

6.3.3.4 The maximum height of the upper panel surface shall not exceed 65 inches from the floor.

6.3.3.5 The sloped surface of the upper panel surface shall begin at a point 48 inches from the floor.

6.3.4 Arm rests shall be provided at all consoles. These rests shall either be a part of the console or a part of the operator's chair.

6.3.4.1 Console arm supports shall provide at least 8 inches and preferably 12 inches of resting surface projecting horizontally across the front of the console.

6.3.4.2 Arm rests integral with the operator's chair shall be a minimum of 2 inches wide by 10 inches long.

6.3.5 If the operator must record data, a writing surface 16 inches in depth is recommended.

6.3.6 Knee and foot room beneath the panel surface shall be provided. The minimum dimensions are: 25 inches high by 20 inches wide by 18 inches deep.

6.3.7 All cabinets, consoles, and work surfaces requiring that an operator stand or sit in close proximity to their front surface shall contain a kick space 4 inches deep by 4 inches high at the base.

6.3.8 Handles on cabinets and consoles shall be recessed when practical to eliminate projections on the cabinet surfaces. Sufficient room to accomodate the hand shall be provided in the grasping of all handles.

6.4 Work Surfaces

6.4.1 Work benches and other work surfaces provided for standing operations shall be 36 inches above the floor.

6.4.2 Desk tops, writing tables, and other work surfaces provided for seated operations shall be 29-30 inches above the floor.

6.4.3 Convenient work surfaces to support job instruction manuals, worksheets, etc., shall be provided where necessary for standing operators of control-display panels.

6.5 Check list for efficient workspace layout

6.5.1 Cabinets, racks, and consoles should be designed with the dimensional statistics of the human operator in mind. Static dimensions are available to the designer, but he must exercise common sense in adjusting these figures to the dynamic situation.

6.5.2 Control-display organization should be such that visual displays generally occupy central areas, and controls occupy peripheral areas, to avoid hand and arm interference with visual tasks.

6.5.3 Where consoles are designed for seated operators, utilize good seating principles such as optimum dimensions with regard to the expected population of users, backrests, armrests, footrests, cushioning, and adjustability.

6.5.4 When desk positions are required, consider height of writing surface, working width and depth, knee and foot room, and elbow room if more than one operator is involved.

6.5.5 Storage space should be designed with man's physical dimensions in mind; consideration should be given to reach distance, eye height when stored items must be seen, and depth of bin when articles get pushed to the rear of the bin.

6.5.6 When men and machines are grouped for system or team operation, consider not only the individual needs but also the equitable flow of human traffic and aura and visual communication links.

6.5.7 When multiple man-machine combinations are grouped together, make sure that operators are not restricted with respect to their primary control manipulations.

6.5.8 When group activity demands use of a central visual display make sure that lines of sight to the display are not blocked by poor arrangement of people or equipments.

6.5.9 Consider the environmental conditions under which the man-machine combination must work. If these conditions cannot be controlled directly, it is necessary for the equipment designer to provide other safeguards. Illumination, temperature, ventilation, and noise are the major environmental considerations, and use of modern protective measures should be part of the design problem.

# 7. HANDLING AND TRANSPORTATION EQUIPMENT

## 7.1 Manual handling of materials

The design and/or procurement of equipment shall consider the following maximum physical limitations on one-man operations. (These limitations generally are not designated for continuously operated controls. Specifications of resistance limitations for hand and foot operated controls are covered elsewhere in this section.)

### 7.1.1 Lifting materials

| Type of movement and/or operation | Maximum allowable weight (lbs) | Height lifted from ground | Distance of CG of object from body |
|---|---|---|---|
| Lifting or short-term movement of materials of a size convenient for handling by one man | 140 | 1' | 0-20" |
| | 135 | 2' | 0-20" |
| | 75 | 3' | 0-20" |
| | 55 | 4' | 0-20" |
| | 35 | 5' | 0-20" |
| | 30 | 1-5' | 24" or more |

### 7.1.2 Carrying materials

| Type of movement and/or operation | Maximum allowable weight (lbs) | Height lifted from ground | Distance of CG of object from body |
|---|---|---|---|
| One-hand (arm at side) | 35 | 30-35" (hand height) | 0-5" |
| Two-hands (arms at side) | 20 (each hand) | 30-35" | 0-5" |
| One-hand (arm bent) | 20 | 30-35" | more than 5" |
| Two-hands (arms bent) | 35 | 30-40" | 0-10" |

Note: Weights whose CG is placed more than 20" away from the body during carrying should be avoided.

## 7.2 Mechanical handling of materials

The following criteria and recommendations generally apply to the safe and efficient operation of mechanical equipment and should be considered in the design, procurement and utilization of these equipments:

### 7.2.1 Positioning equipment

#### 7.2.1.1 Cranes (hand, electric, engine)

7.2.1.1.1 When a hand crank is used, the maximum resistance limitations appearing elsewhere in this section shall apply.

7.2.1.1.2 The main boom shall be provided with an angle indicator designed so as to be easily read by the operator from his working position.

7.2.1.1.3 A permanent placard of operating instructions which can be easily read and followed by the operator, shall be provided and located on the equipment. Wherever applicable, these instructions shall indicate all information necessary to the correct operation and/or maintenance of the equipment (e.g., maximum loads, etc.).

7.2.1.2 Equipment slings and hoists

Hoist points for sling attachments shall be clearly marked on equipment for easy visual identification. This includes both the lifting apparatus and the materials to be lifted.

Note: Stops, chocks, rails, etc. shall be included where feasible to provide aids in positioning equipment and in preventing injury to both operator and equipment.

7.2.2 Transporting equipment

Vehicles requiring manual steering through the towbar shall be provided with an adequate mechanical advantage to permit the easy one-man movement of the wheels under static full-load conditions. In addition, some consideration should be given to the size of the turning radius and provision for towbar stops. Size and weight are important considerations in determining turning radius. A relatively short turning radius is desirable for one-man manual towing. Towbar stops are necessary to prevent undesired bar travel.

7.2.3 Resistance limitations for hand and foot controls on material handling equipment

Most equipment controls (levers, pedals, cranks, etc.) possess a certain amount of built-in resistance to movement. The following maximum limits apply to commonly used controls.

| | Motion of control | Maximum resistance of control (lbs.) |
|---|---|---|
| 7.2.3.1 | Lateral motion of lever type controls | 20, one hand<br>30, two hands |

| | | |
|---|---|---|
| 7.2.3.2 | Fore-aft push-pull motion on lever type controls mounted along the median plane of the body | 50, one hand<br>65, two hands |
| 7.2.3.3 | Pushing or pulling hand levers of the gear-shift type | 30 |
| 7.2.3.4 | Turning hand wheel (minimum 7 inch diameter) | 50 (measured as force applied at circumference of the control) |
| 7.2.3.5 | High-speed steady turning of small crank (less than 3 1/2 inch radius) | 5 (measured as in 7.2.3.4) |
| 7.2.3.6 | High-speed steady turning of larger cranks (greater than 3 1/2 inch radius) | 10 (measured as in 7.2.3.4) |
| 7.2.3.7 | Operation of pedal control by ankle flexion | 20 |
| 7.2.3.8 | Operation of pedal control by leg movement (braced by seat) | 180 |

## 8. DESIGN OF EQUIPMENT FOR MAINTAINABILITY

### 8.1 General

A major problem faced by the military services is effective maintenance of complex electronic equipments despite shortages of highly skilled maintenance technicians. This section is intended to help alleviate this problem by recommending design practices which will maximize the ease with which electronic equipment can be maintained. It should be noted that maintenance, as referred to in this section, includes inspecting, checking, trouble shooting, adjusting, replacing, repairing, and servicing.

### 8.2 Accessibility

#### 8.2.1 Housing

8.2.1.1 Covers and cases shall have rounded corners. Minimum radius of curvature shall be 1/8 inch.

8.2.1.2 Ventilation holes shall be sufficiently small so as to prevent the insertion of test probes or screw drivers or other tools.

8.2.1.3 The housing should include space enough to clear connecting wires and sealing materials.

8.2.1.4 Equipment housing shall be designed to maximally facilitate the removal of the assembly. Where applicable, the use of removable housing rather than equipment provides advantages in accessibility and should be considered.

8.2.1.5 The use of sliding rack mounting should be considered for larger electronic packages or units which cannot be broken down easily into smaller components.

8.2.2 Handles

8.2.2.1 Handles shall be provided on covers, shields and hoods to facilitate access to and removal of the enclosed components.

8.2.2.2 Handles shall be designed to fit the particular mode of access and should take into account gloves and/or other protective equipment worn by the operator.

8.2.2.3 The following dimensions are minimum for handles to be used by the ungloved hand.

| Weight to be lifted or moved | Minimum handle Diameter | Minimum finger Clearance | Minimum handle width |
|---|---|---|---|
| Up to 25 lbs. | 1/4-1/2" | 2" | 4-1/2" |
| Heavier | 1/2-3/4" | 2" | 4-1/2" |

8.2.2.4 Recessed, rather than extended handle fixtures, are recommended for vertically mounted racks or any area wherein it would be possible for the operator to strike the handles in his normal movements.

8.2.2.5 Hoist and lift points which are not supplied with handles shall be clearly marked as lift points and shall be marked as to the weight or stress limits allowed.

8.2.3 Access space and covers

8.2.3.1 Physical access shall be provided whenever equipment must be reached or operations performed on enclosed components.

8.2.3.2 Components shall be directly available through access doors.

8.2.3.3 Access covers shall be hinged if space permits.

8.2.3.3.1 The weight of access doors (including accessories) shall not exceed specifications for lifting and lowering approximately as set forth in Section 7.1

8.2.3.3.2 When access covers are hinged at the top, they shall be provided with a support rod to insure safe utilization.

8.2.3.4 Visual access apertures shall be uncovered. Where environmental or structural conditions necessitate, a clear transparent window shall be used.

8.2.3.5 Size of access covers shall be determined by the task involved.

8.2.3.5.1 For one-hand tasks, the minimum access dimensions shall be 4" x 4".

8.2.3.5.2 For two-hand tasks, the minimum access dimensions shall be 8 inches larger than the greatest dimension of the equipment to be handled.

8.2.3.5.3 Where large components requiring two-hand movement are enclosed in cabinets, their handles shall be placed no more than 22 inches from the access cover.

8.2.3.6 Each access cover shall be labeled according to its prime function, symbol designation or items accessible.

8.2.3.7 Where tubes or plugs must be inserted through small accesses, an external label should indicate the proper orientation of the tube or plug.

8.2.4 Fasteners

8.2.4.1 Fasteners of the quick-release type shall be used with frequently serviced equipment.

8.2.4.2 Retained fasteners shall be used on all removable cover-plates.

8.2.4.3 Hand-operated fasteners are preferred for frequently serviced equipment. However, fasteners requiring standard tools (screw driver and wrench)are acceptable. All fasteners requiring the use of non-standard tools shall be avoided.

8.2.4.4 A combination slot arrangement and hex head should be used so that the bolt or fastener can be opened with an ordinary screw driver and, in the case of a jammed bolt, with a wrench.

8.2.5 Labeling and coding of units

8.2.5.1 All units shall be labeled so as to facilitate identification, requisitioning and replacement.

8.2.5.2 Identification markings on units shall be located and readily accessible and/or visible with minimum disassembly.

8.2.5.3 Permanent labels and markings shall be etched or embossed into the component or chassis, or on the identification tag.

(Where other than etched or embossed labels must be used, printed decals or stamped letters shall be used.)

8.3 Adjustment, alignment or checking of equipment

8.3.1 Units shall be constructed to provide for individual unit calibration, alignment and/or adjustment. The units should then be capable of being joined into a functional grouping without the necessity of many additional adjustments.

8.3.2 Connection points for the attachment of service and test equipment shall be easily accessible and equipped with fittings of the quick-connector-release type.

8.3.3 The practice of blind adjustments shall be avoided. All adjustments shall be visible to the operator. In addition, screw type adjustments should be located so that the screw driver or alignment tool is in the vertical position and/or is provided with a guide to maintain the correct adjusting angle.

8.3.4 Wiring diagrams and location diagrams shall be provided for all circuits in a readily visible location.

8.3.5 Lubrication points and fittings on all equipments shall be easily accessible. Sealed lubrication should be used wherever possible.

8.3.6 Where the operator must connect input or output lines to test equipment, these couplings shall be coded so that their relationship to the test panel controls and/or displays is clear. This requirement can be implemented through the use of color and/or numeral and/or letter coding.

8.4 Assembly and disassembly

Note: This includes the repair, removal and replacement of parts.

8.4.1 Equipment design and/or procurement shall provide for as many interchangeable standard parts as practicable.

8.4.2 Interchangeable and removable parts shall, wherever possible be designed so that they can be installed in only the proper position.

8.4.3 All assemblies should be replaceable with the use of ordinary hand tools and, as far as possible, with a minimum number of different tools.

8.4.4 Mounting bolts and fasteners shall be located so that they are easily accessible to the technician.

Plug-in type units shall be provided for equipment which must be serviced in the field.

8.4.5 Guide pins, indexing the correct placement of parts and units, or other indexing arrangements, shall be used wherever applicable.

8.4.6 The use of tools for tube removal and installation is not recommended and should be avoided in the design of electronic components. In addition, the removal of tubes shall not require the removal of other components.

8.4.7 Fuses shall be located in readily visible and accessible places. Their replacement shall not require the use of tools.

8.4.8 Safety covers shall be provided for voltage potentials of 40 or more volts where interlocks are not provided. Where voltage potentials of 220 volts exist, labels indicating high voltage should be attached.

8.4.9 Cables and connectors

8.4.9.1 Circuits shall be designed so as to minimize the number of connections between units.

8.4.9.2 Cables and connectors shall be routed so that they cannot be pinched or harmfully bent by the action of doors, cases, lids, access covers, etc.

8.4.9.3 Cables and connectors installed on packaged units shall be prevented from being used as hand holds or steps. This can be done by shielding or guarding, or markings designed to prevent such abuses.

8.4.9.4 Cable routing shall be accessible to the technician without the need of dismantling structures or excessive removal of components. Serious attention shall be given the routing of cables from this maintenance point of view.

8.4.9.5 Multi-strand or coaxial cables shall be fanned for check or troubleshooting purposes at readily visible and accessible locations. Markings on each wire shall be designed to be legible to the technician within the working area.

8.4.9.6 Connectors (Jones, Cannon plugs, etc.) shall be designed, procured and/or used so that it is impossible to mis-mate them. Physical interference such as indexing lugs or non-symmetrical hole patterns shall be provided to insure the replacement of the right fittings into the right sockets. Indication of the index shall be made on the receptacle and the plug.

8.4.9.7 Connectors shall be coded to their mates. This can be accomplished in a number of ways. The requirements for coding in this regard also include that of consistency in the use of the adopted coding measures. The following coding procedures may be used in addition to the indexing specified in the preceeding paragraph.

a. Use different sizes of connectors where there are multiple adjacent connections to be made.

b. Color coding may be used to specify different lines and their related connections.

8.4.9.8 All Connector pins shall be coded (numerical markings or otherwise) so as their function can be easily determined.

8.5 Summary of steps in designing for maintainability

| Stage of equipment design | Steps in designing for maintainability |
|---|---|
| Preparation of planning documents | 1. Prepare realistic objectives for maintainability |
| Study of previous system | 2. Review experience on previous systems for application to maintainability of new system |
| Development of breadboard and experimental models | 3. Establish adjustment points and self-compensating features |
| Design of developmental model | 4. Determine maintenance levels<br>5. Divide equipment into units<br>6. Prepare maintenance procedures<br>7. Determine requirements for maintenance supports<br>8. Review and modify design for maintainability<br>9. Translate design for maintainability into actual equipment and maintenance instructions |
| Testing of developmental model | 10. Make preliminary tests of maintainability and modify design as necessary |

| | |
|---|---|
| Testing of service test model (operational suitability test) | 11. Make full scale tests of maintainability and modify design as necessary |
| Evaluation of prototype (pre-production) model | 12. Evaluate maintainability of the system |
| Engineering changes | 13. Correct deficiencies in maintainability of production equipment<br>14. Review engineering changes for effect on maintainability |

9. HAZARDS AND SAFETY

As part of inertial guidance equipment design, safety factors are of primary importance. The following safety considerations shall be applied, where applicable. This list is by no means complete, and includes only representative items.

9.1 Insure that conspicuous placards are mounted adjacent to high voltage, very hot, etc., equipment.

9.2 Operation of switches or controls which initiate hazardous operations shall require the prior operation of a related or a locking control. Where practicable, the critical position of such controls shall activate a warning device in the affected area.

9.3 A hazard alerting device should be provided to warn personnel of impending hazards (i.e. fire, presence of gas, etc.)

9.4 Provide a guard on all moving parts of machinery and transmission equipment, including pulleys, belts, gears, etc., in which personnel may become injured or entangled.

9.5 Incorporate self-locking or other foolproof devices on elevating stands, jacking devices and work platforms to prevent accidental or inadvertant collapse.

9.6 When applicable, distinctly mark the center of gravity of equipment.

9.7 Provide portable hand operated fire extinguishers in areas where fire hazards exist or may be created.

9.8 Provide for neutralization or flushing of harmful materials spilled on equipment or personnel (i.e. battery acid).

9.9 Indicate the weight capacity on stands, hoists, lifts, jacks, and similar weight bearing equipment to prevent overloading.

9.10 Jacking and hoisting points shall be conspicuously and unambiguously identified.

9.11 Wiring shall be routed through plugs and connectors so that removal of a plug or connector does not expose hot leads.

9.12 Insure that adequate illumination is provided in all areas. Work areas should be illuminated by at least 25 foot candles.

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